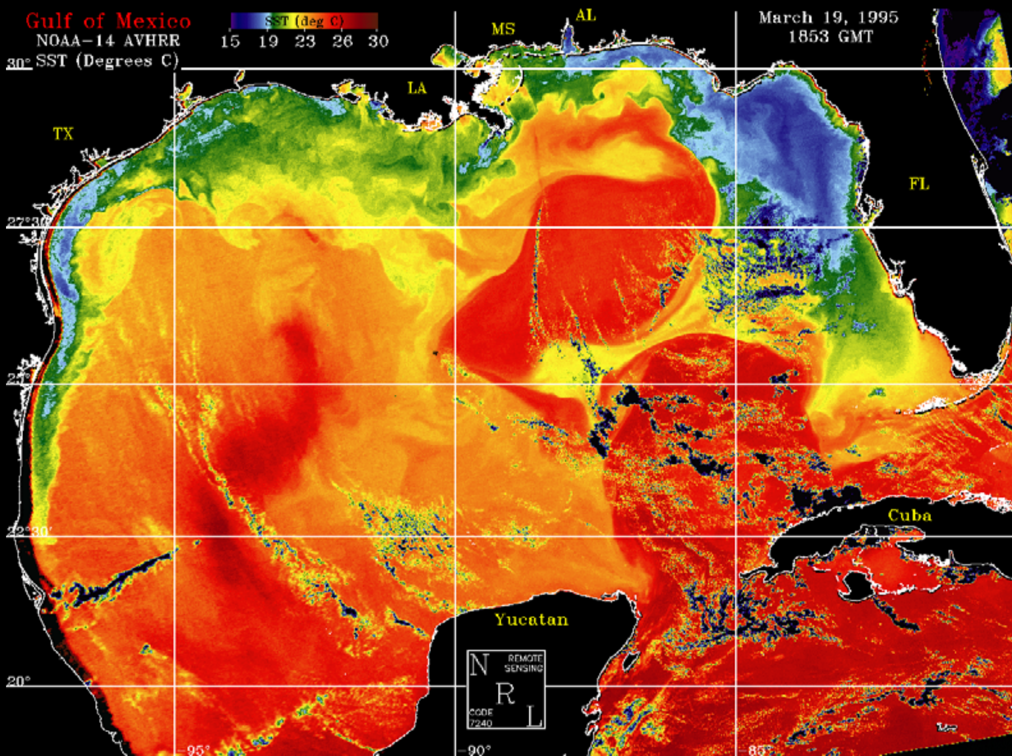
# Satellite Technology and Fisheries in the Northern Gulf of Mexico

Part I: Hydrodynamics of the GOM

Don Johnson, Naval Research Lab - SSC

A. Using satellite technology to define ocean processes of interest to fisheries - Advection and water properties.

B. The Loop Current - A major contributor to ambient conditions.



# Outline:

**AVHRR**

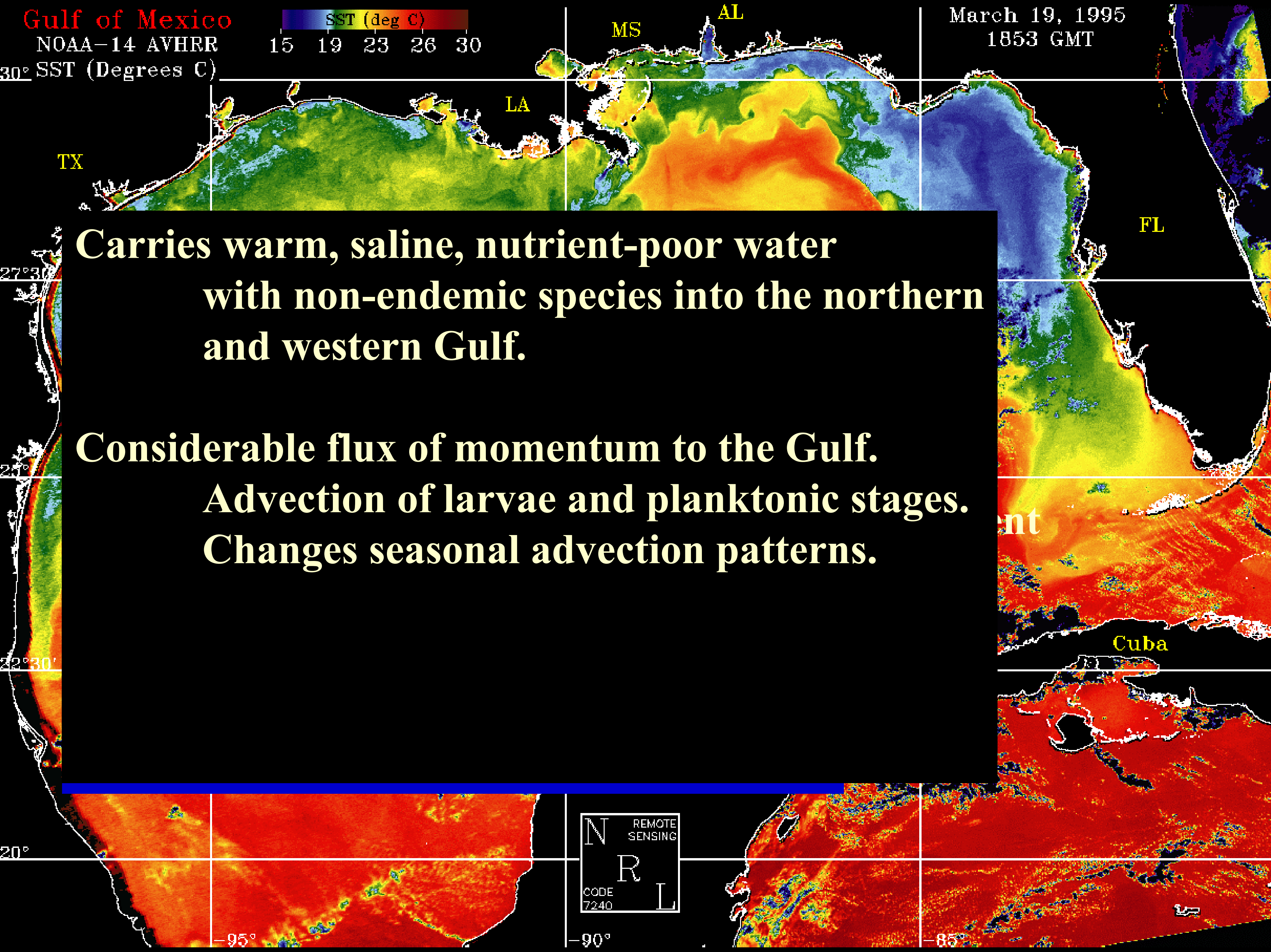
- Loop Current/Spin-off eddies
- topography/currents
- LC research history
- Interaction with shelf
- clouds
- summer heating

**Altimeter**

- Geostrophy-Sea level
- geoid/sea level anomaly
- basin-scale currents
- data assimilation

**Color**

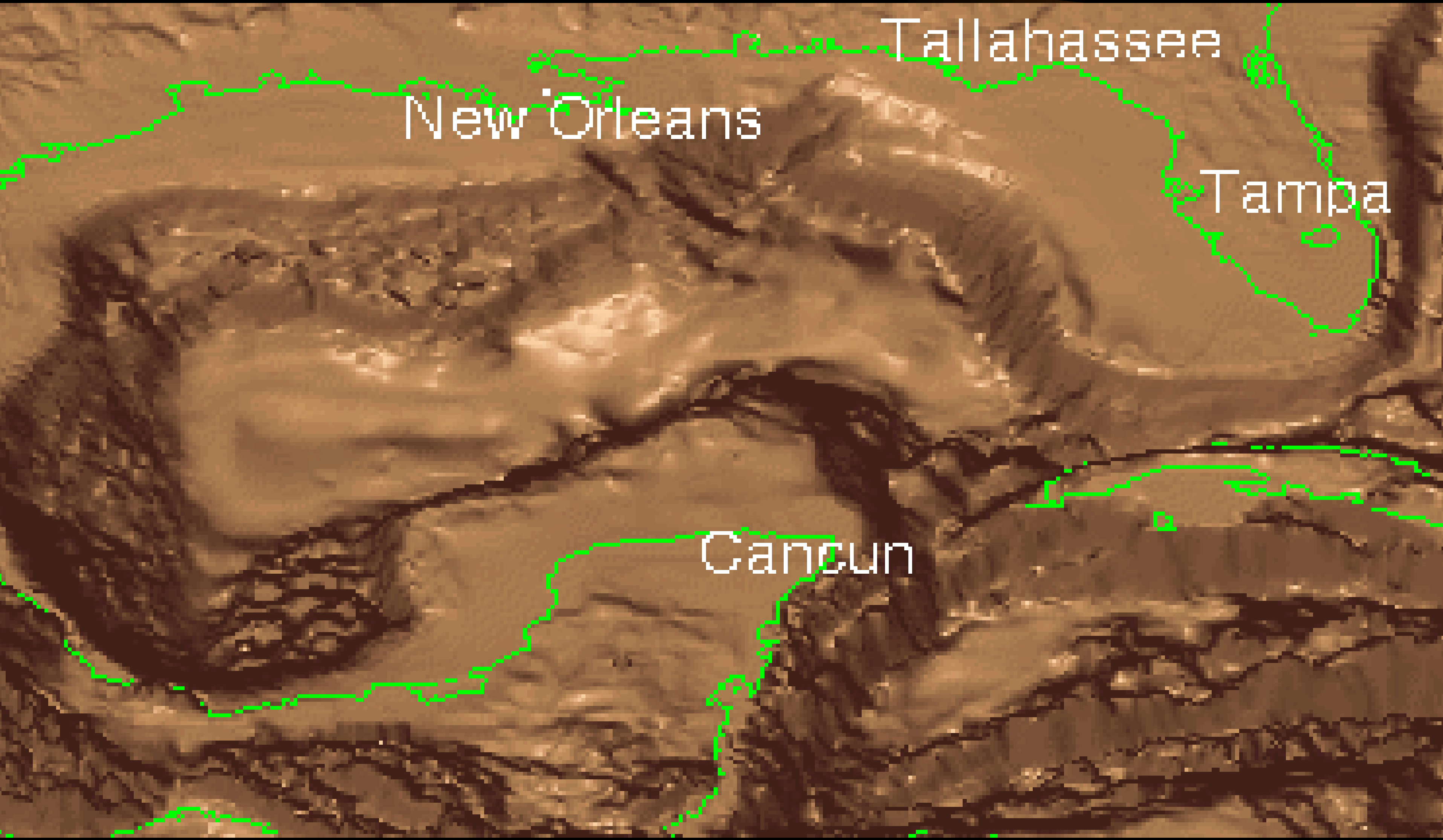
- SeaWifs
- Reflectance spectrum
- Inherent optical properties
- Phytoplankton spectra
- Chlorophyll, dissolved organics & detritus



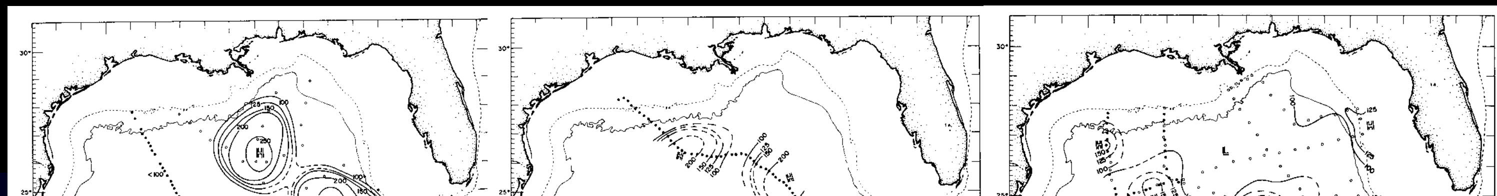

Carries warm, saline, nutrient-poor water
with non-endemic species into the northern
and western Gulf.

Considerable flux of momentum to the Gulf.
Advection of larvae and planktonic stages.
Changes seasonal advection patterns.

# GOM topography (FSU)



# Early investigations by the Texas A&M and AOL-Miami Gang.



Mid-1970’s thermal imagery began to be an effective tool.

Molinari et al. (1977).  Hey there’s a winter intrusion.

Hulbert and Thompson (1980).  Numerical model showed that intrusion and break-off is an instability process.

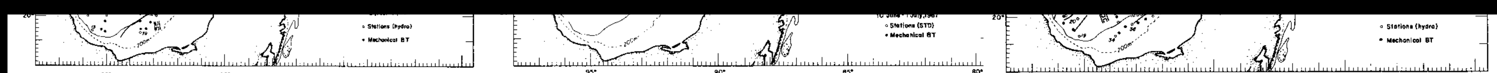




FIG. 5. Topography of the 20°C isothermal surface as determined from hydrographic and MBT data collected during cruise 12 of the Bureau of Commercial Fisheries vessel R.V. *Geronimo* in February and March 1967. Script numbers identify the station numbers.

FIG. 6. Topography of the 20°C isothermal surface as determined from STD and MBT data collected during cruise 4 of the R.V. *Alaminos* during June 1967. See Nowlin and Hubertz (1972) for station numbers and MBT positions.

FIG. 8. Topography of the 20°C isothermal surface as determined from hydrographic and MBT data collected during cruise 16 of the Bureau of Commercial Fisheries vessel R.V. *Geronimo* in August and October 1967. Script numbers identify the station numbers.

During 1950’s and 1960’s numerous ship surveys had mapped the basic loop current and eddy system.

# *Spin-off eddies have deep structure.*

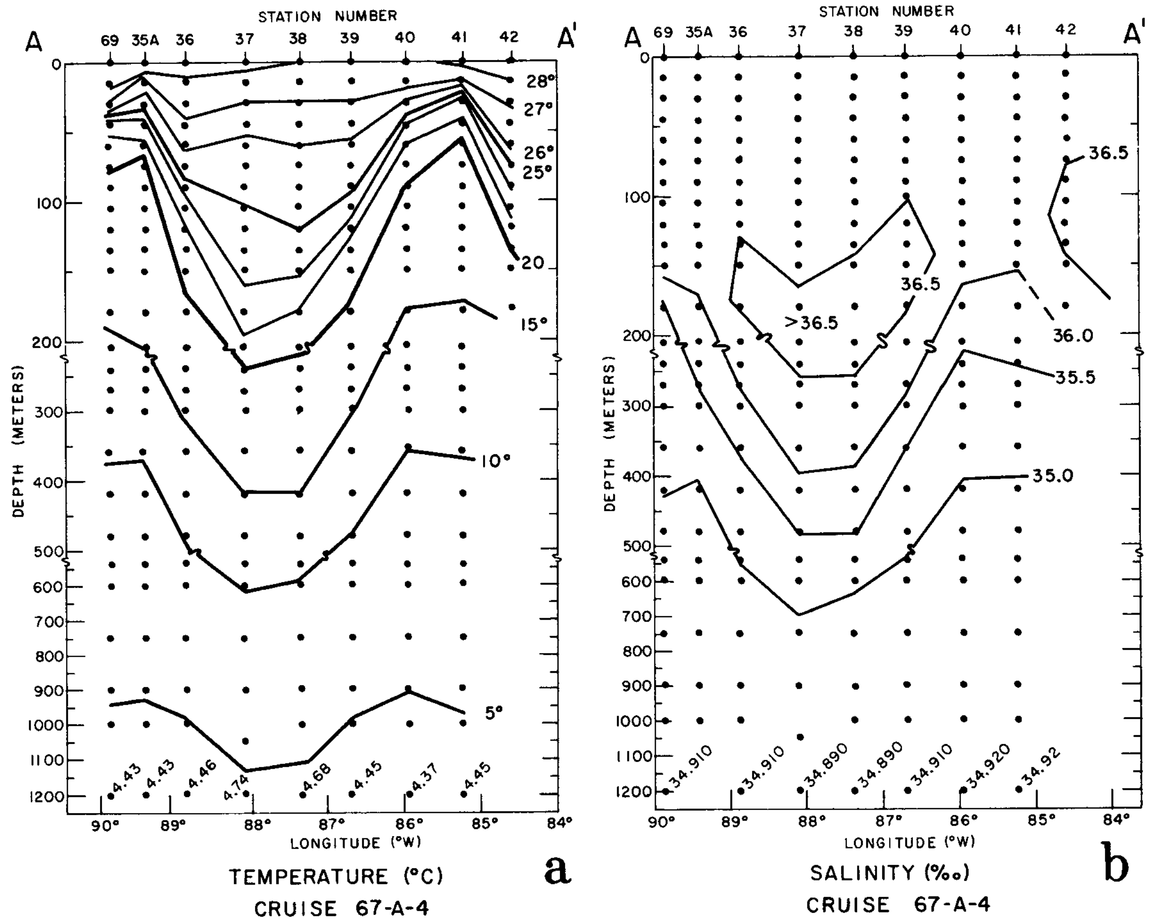
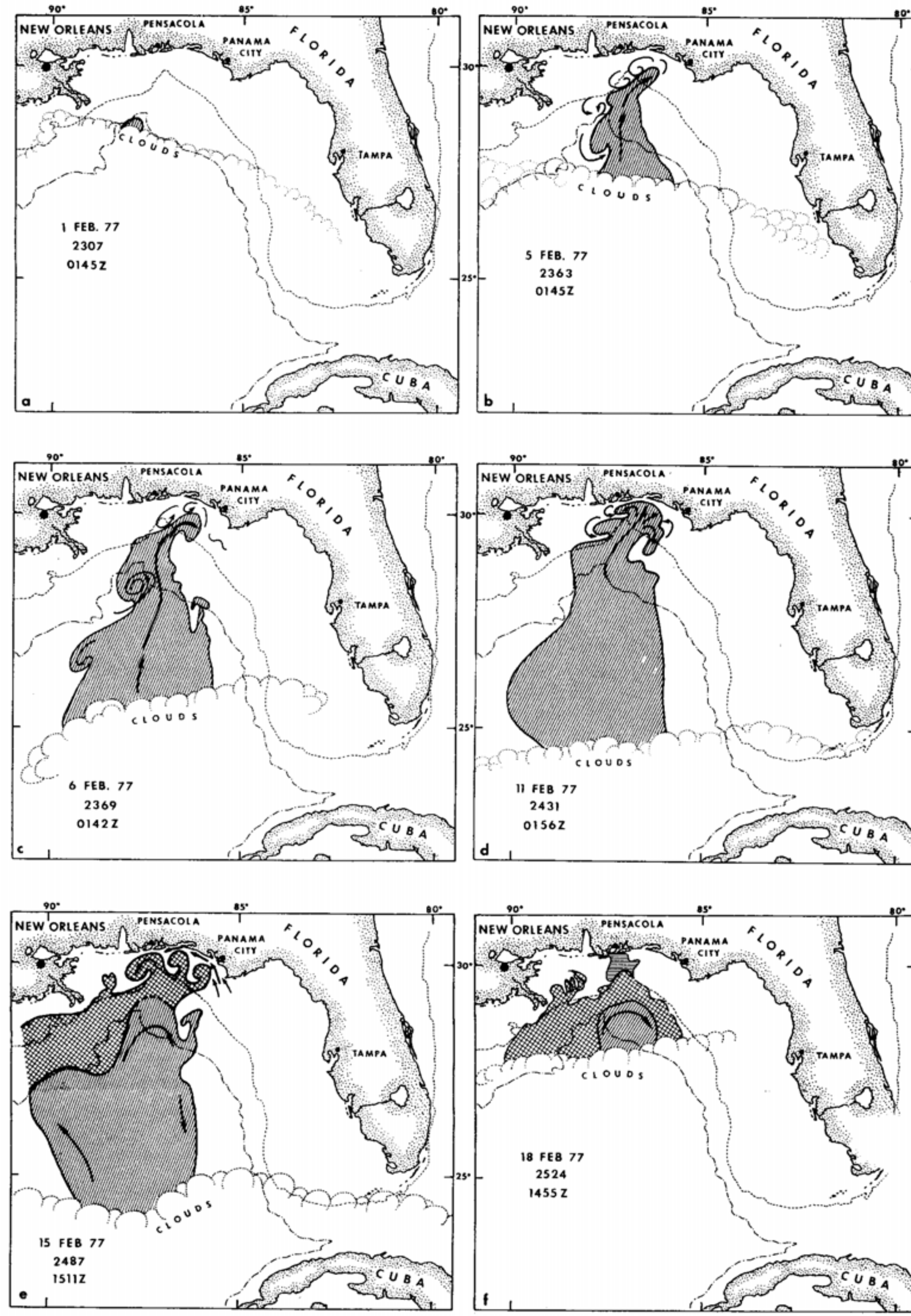



FIG. 1. Vertical sections of (a) temperature and (b) salinity along the line A–A′ through the anticyclonic ring shown in Fig. 6. The stations are plotted by longitude so that the section is skewed, stations on the right being farther to the north than stations on the left. Note, too, that there are two scale changes in the depth scale.

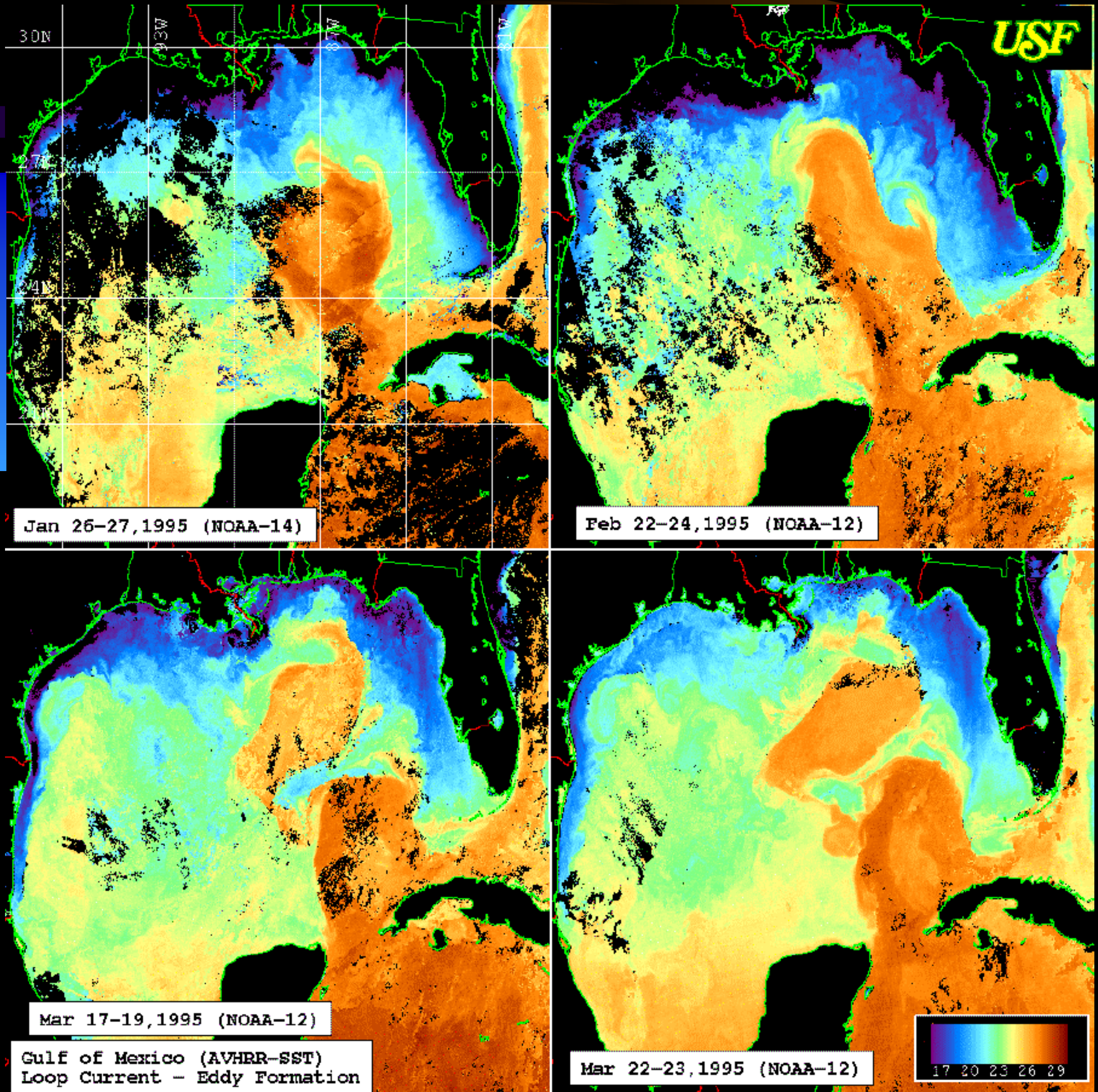
# Intrusion onto the shelf: Huh et al. (1981).



# Two big problems with passive sensors:

## Clouds:

**Solution - composite maximum temperature at each pixel.**

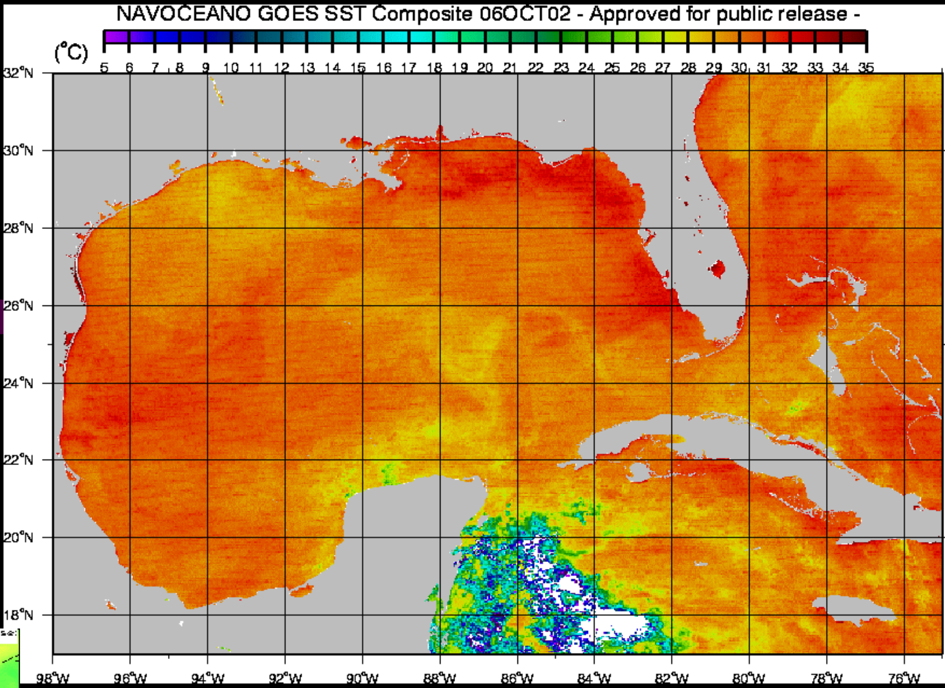


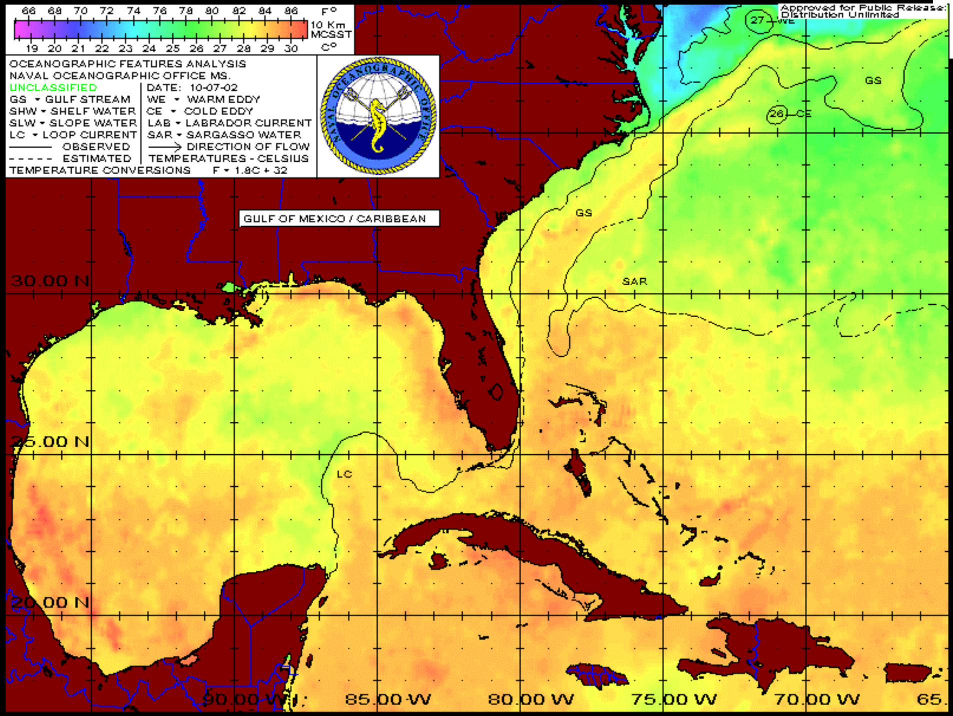
# Summer heating of the GOM

**Solutions:**

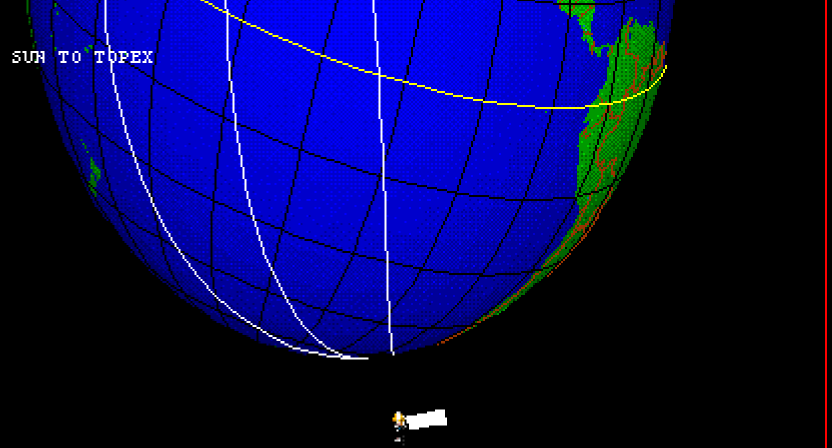
altimetry - deep basin

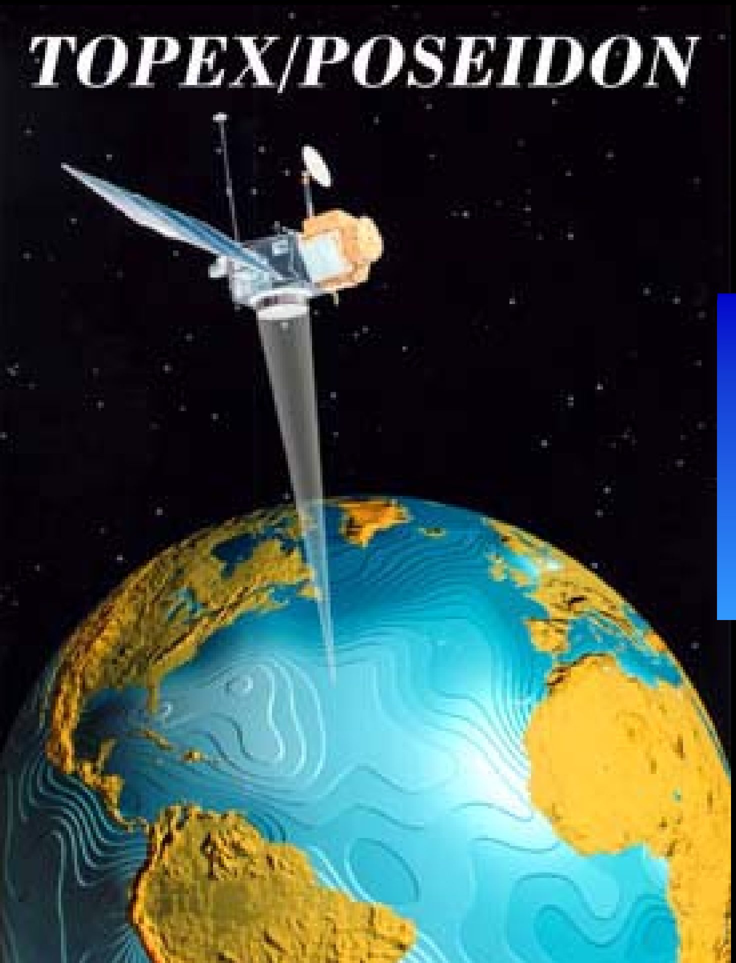
color - shelf



Satellite Altimeter
radar distance to ocean surface




Repeats same pattern of tracks.
10 day repeat cycle.

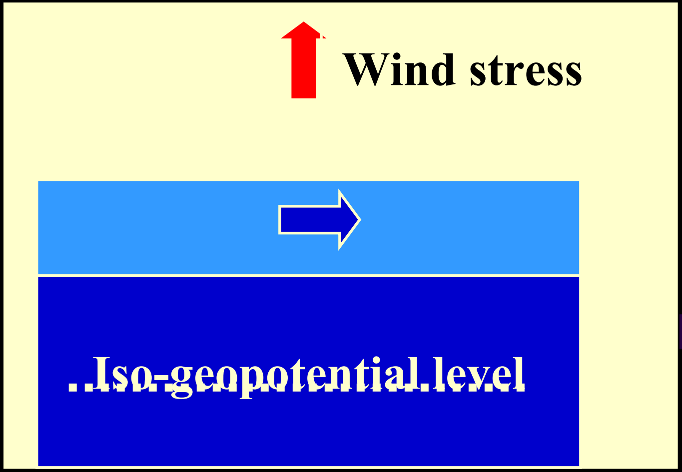
**Advantages:**

- "Sees" through clouds.
- Gets a "dynamic" quantity
  - pressure highs and lows

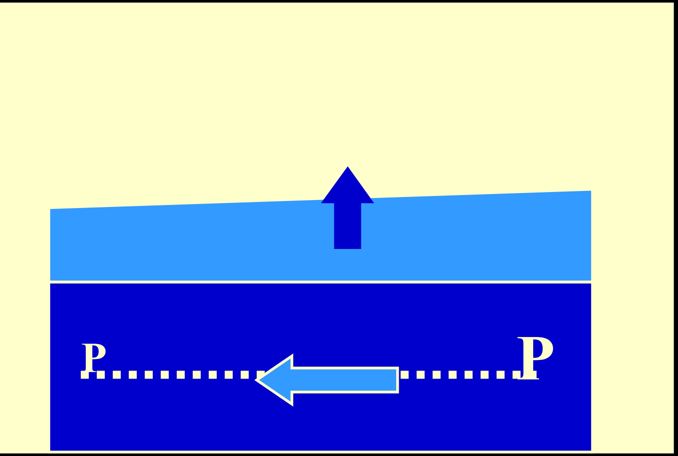
**Disadvantages:**

- Nadir view
- Geoid and tide noise

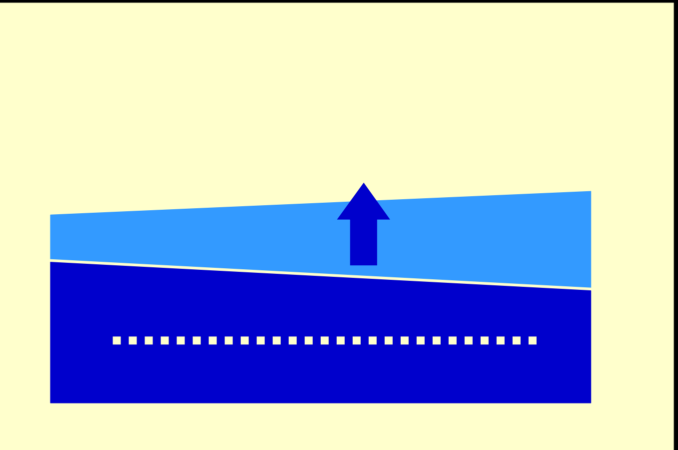
# Geostrophic flow and sea level




End view of Florida Straits
with light water over heavy water.
Wind begins to blow toward the north.

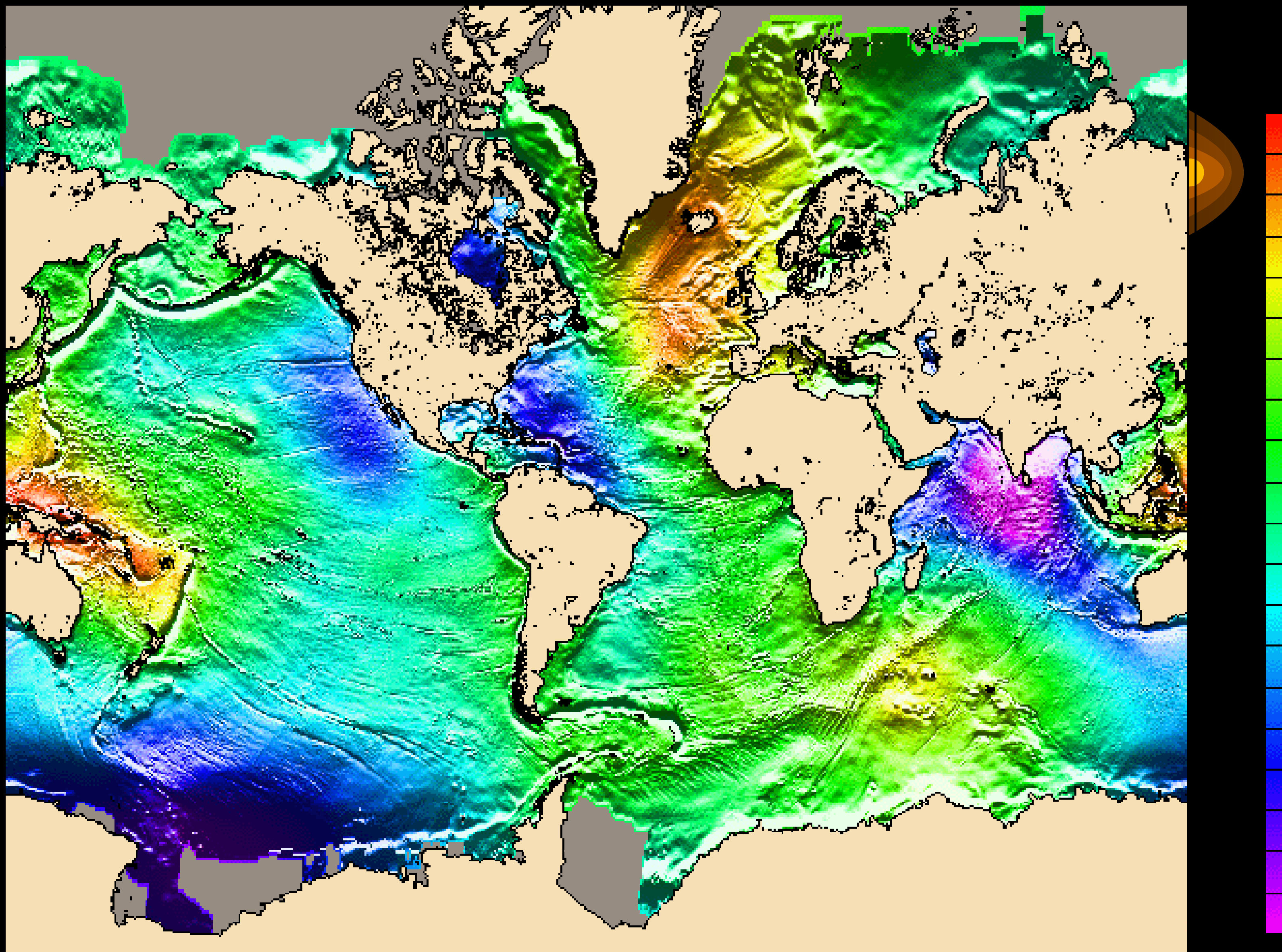



Upper layer water goes to right and piles up against Bahamas.
Pressure gradient at deep level causes flow to left - piling up against Miami.



Pressure balance restored with upper layer flowing north and higher sea level to the right. **Currents are proportional to sea level gradient.**

# Marine "geoid" = average level of ocean wrt reference ellipse

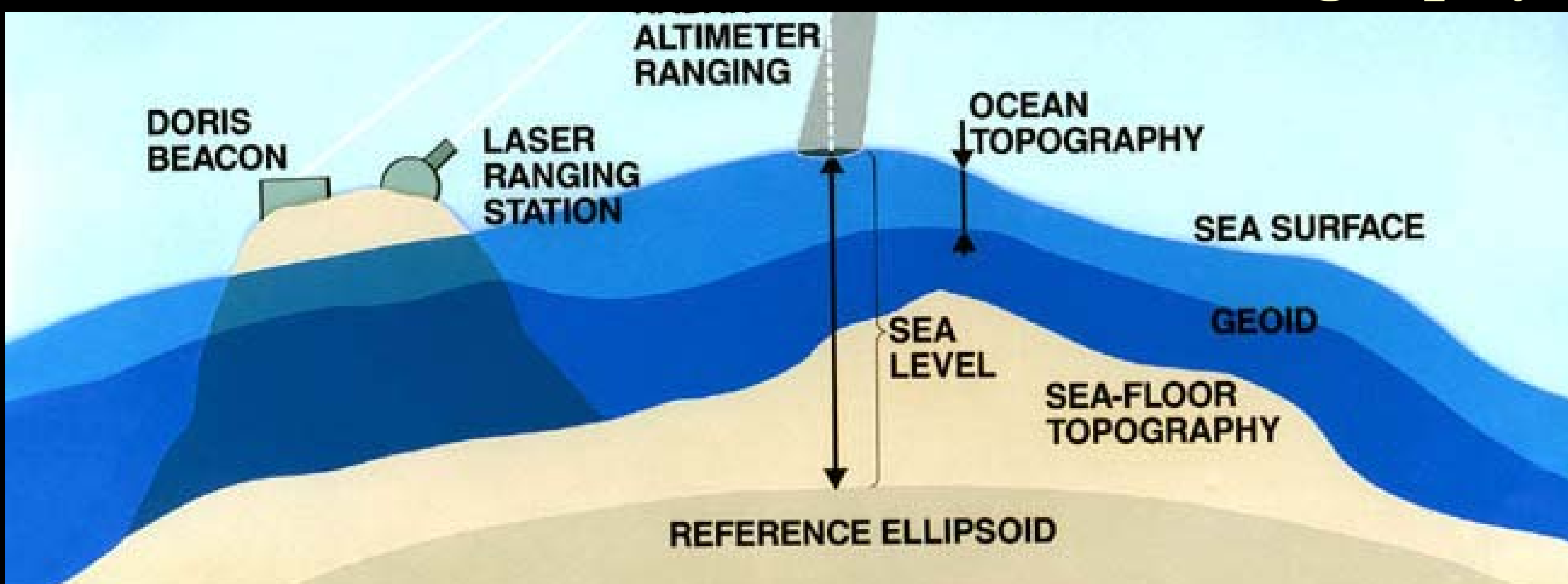


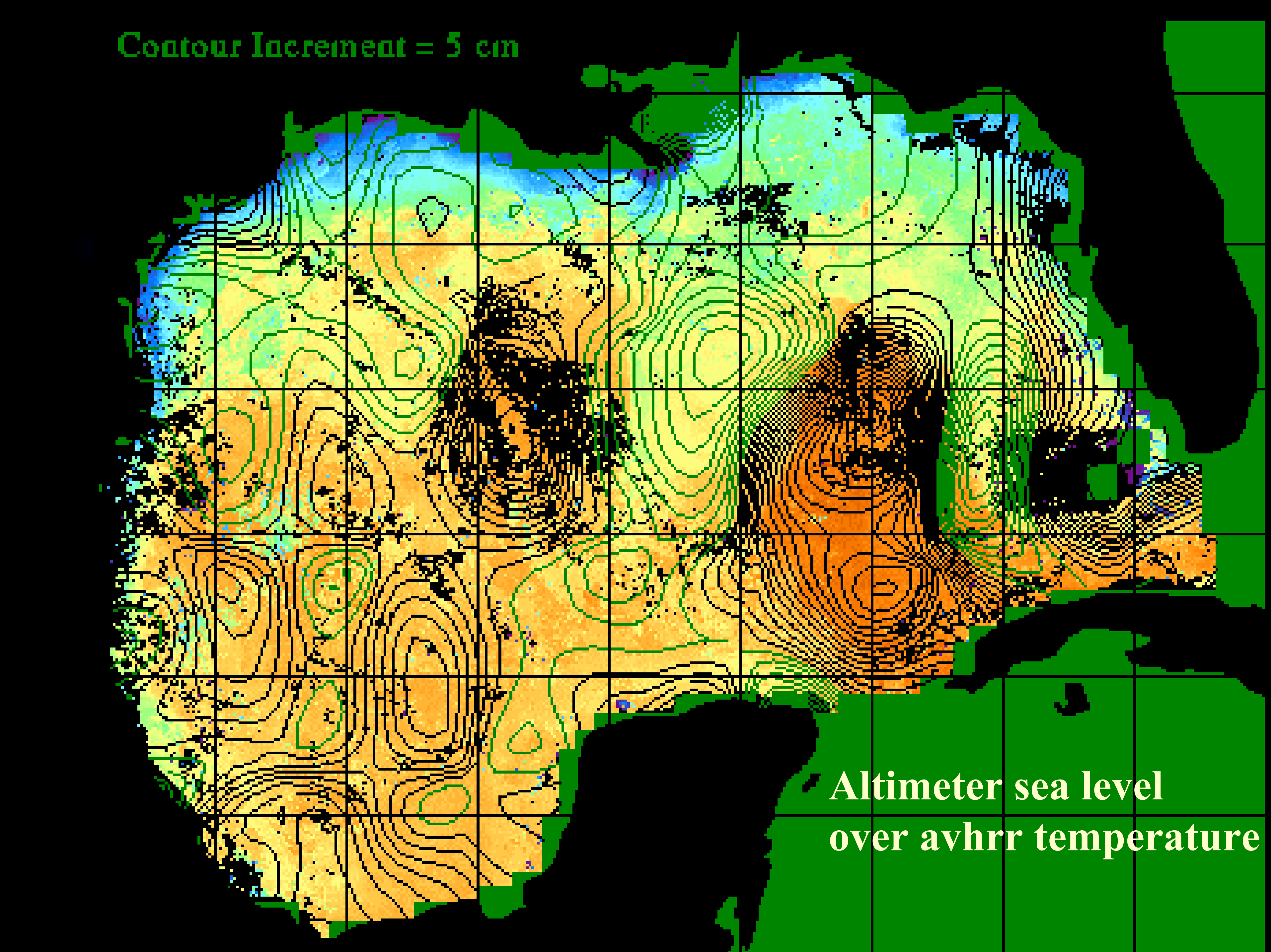

**Take average of repeat track sampling.**

**Call this the ‘Geoid’**

**Take deviation from ‘Geoid’ as oceanography.**

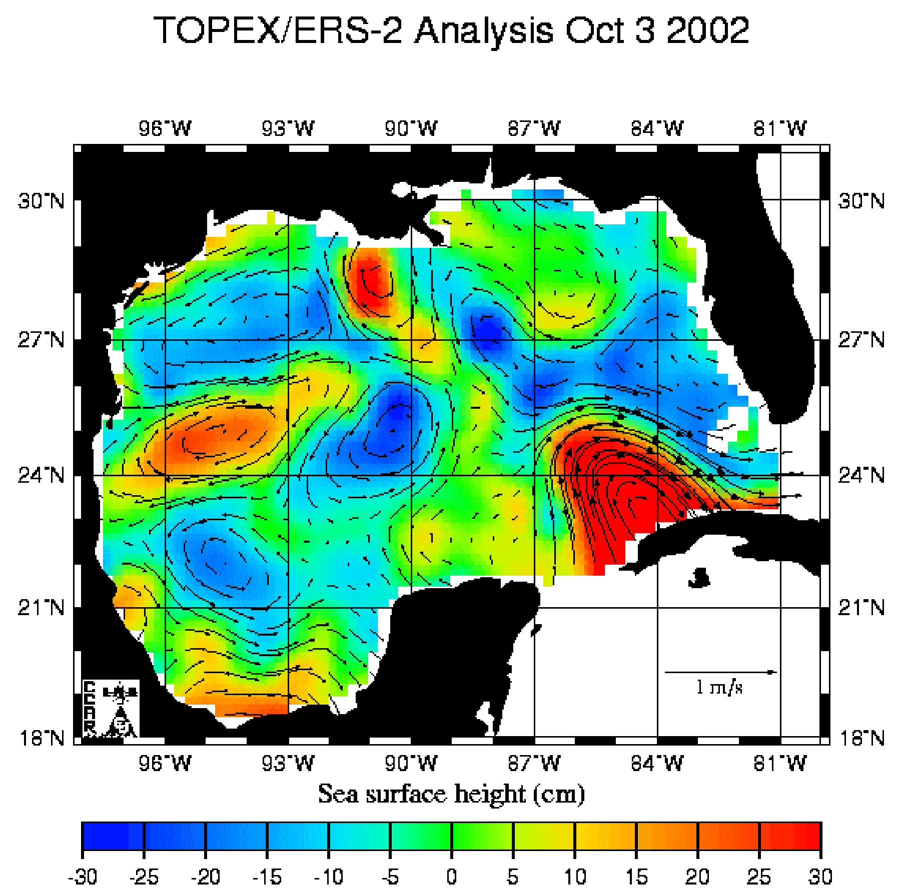
**But this removes the mean oceanography.**

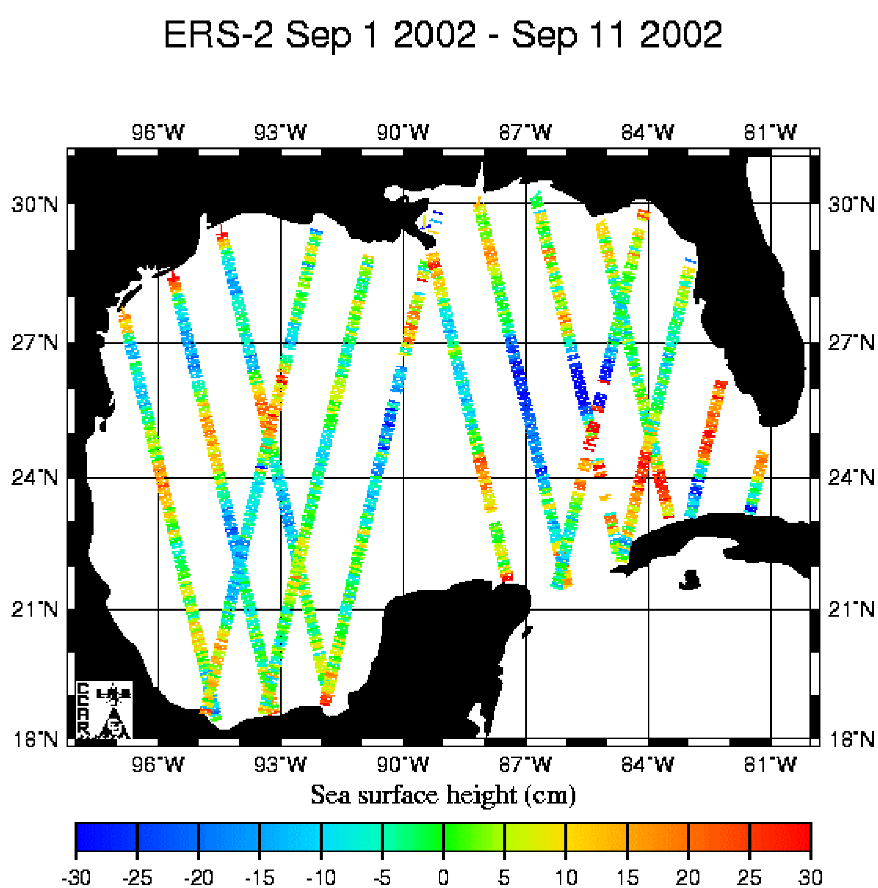



Contour Increment = 5 cm
Altimeter sea level
over avhrr temperature

Bob Leben's web site
U. Colorado - ccar

Widely spaced measurements




"anomaly added to model mean.

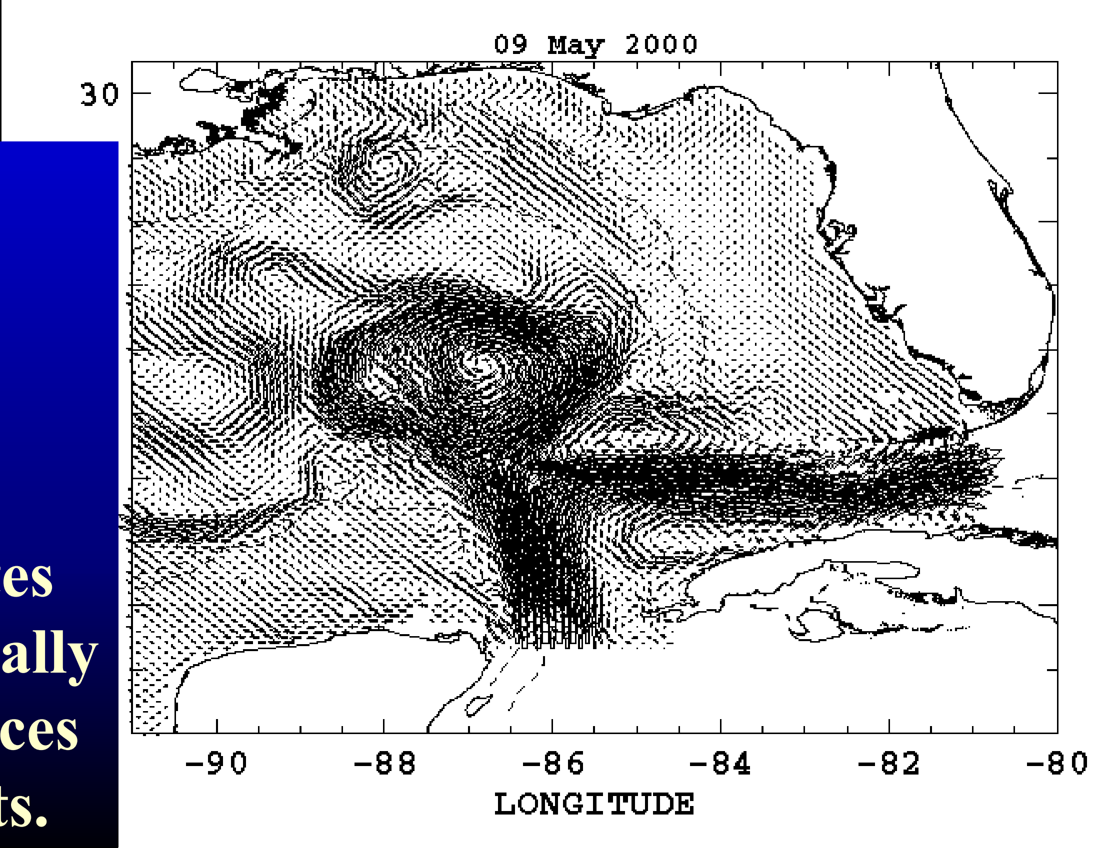
Good for deep basin but NOT FOR SHELVES AND SLOPES! Geoid and tide!

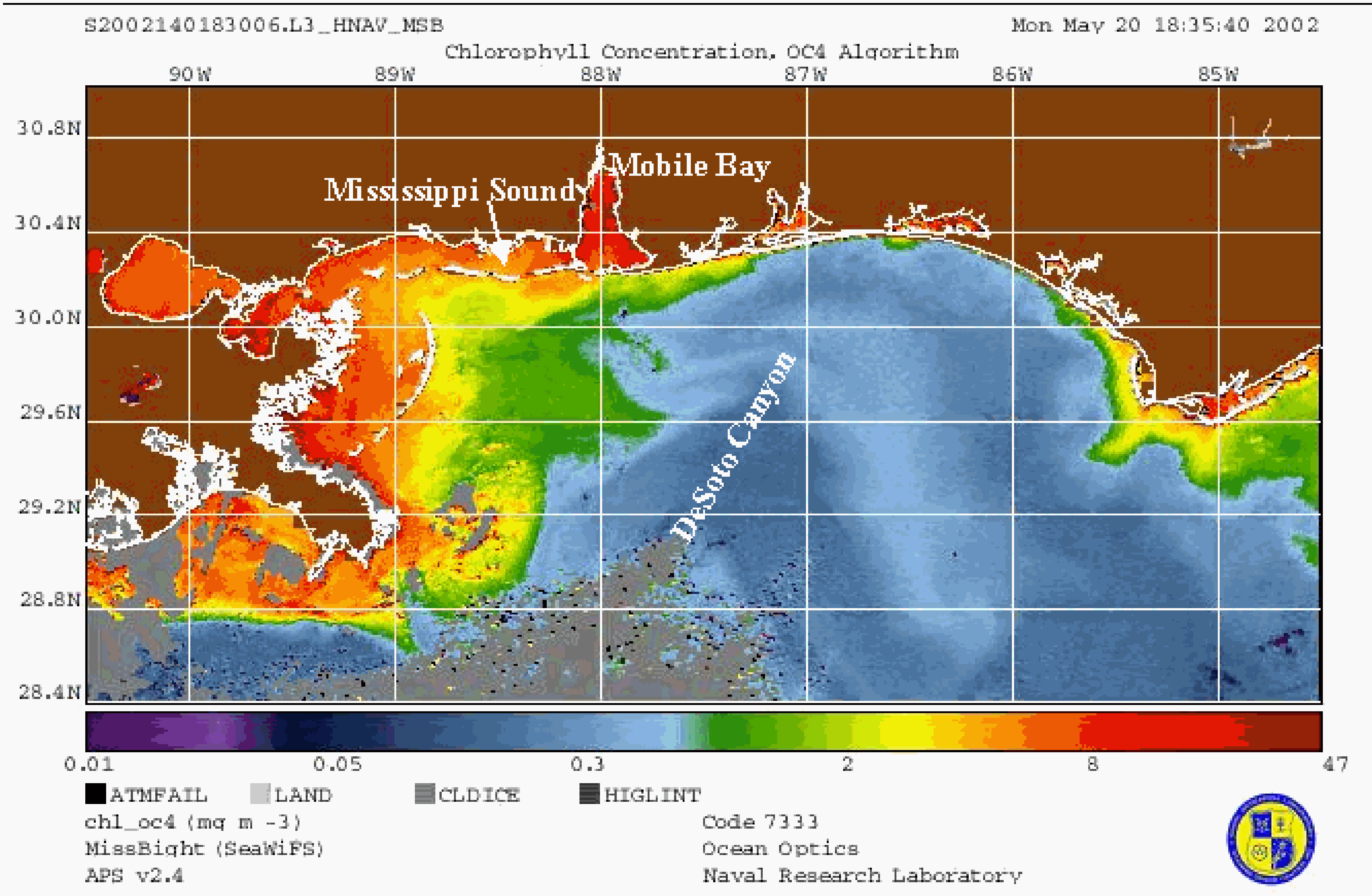
# Altimeter data assimilation into models: An answer to two problems.

1. Widely spaced sampling tracks (space and time).
2. Modeling an inherently non-predictable system.

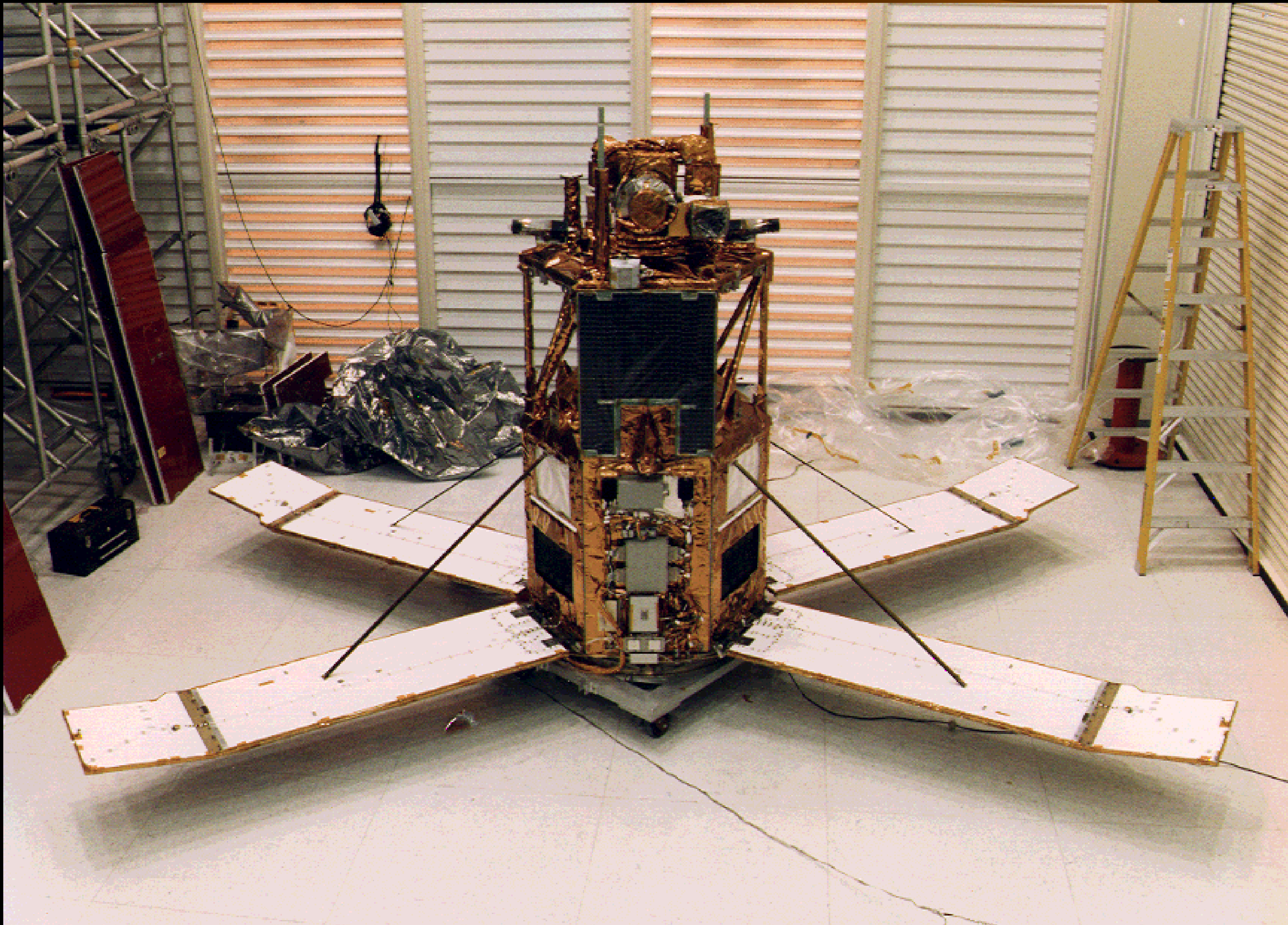
From the modeler's point of view, data assimilation 'phases' the model.

From the altimetrist's point of view, the model interpolates between tracks in a dynamically consistent manner and replaces shelf and slope measurements.




S2002140183006.L3_HNAV_MSB
Mon May 20 18:35:40 2002
Chlorophyll Concentration, OC4 Algorithm
90W
89W
88W
87W
86W
85W
30.8N
30.4N
30.0N
29.6N
29.2N
28.8N
28.4N
Mobile Bay
Mississippi Sound
DeSoto Canyon
0.01
0.05
0.3
2
8
47
ATMFAIL
LAND
CLDICE
HIGLINT
chl_oc4 (mg m -3)
MissBight (SeaWiFS)
APS v2.4
Code 7333
Ocean Optics
Naval Research Laboratory

# *SeaWIFS: Color satellite*



# SeaWiFS: *Daily Coverage*

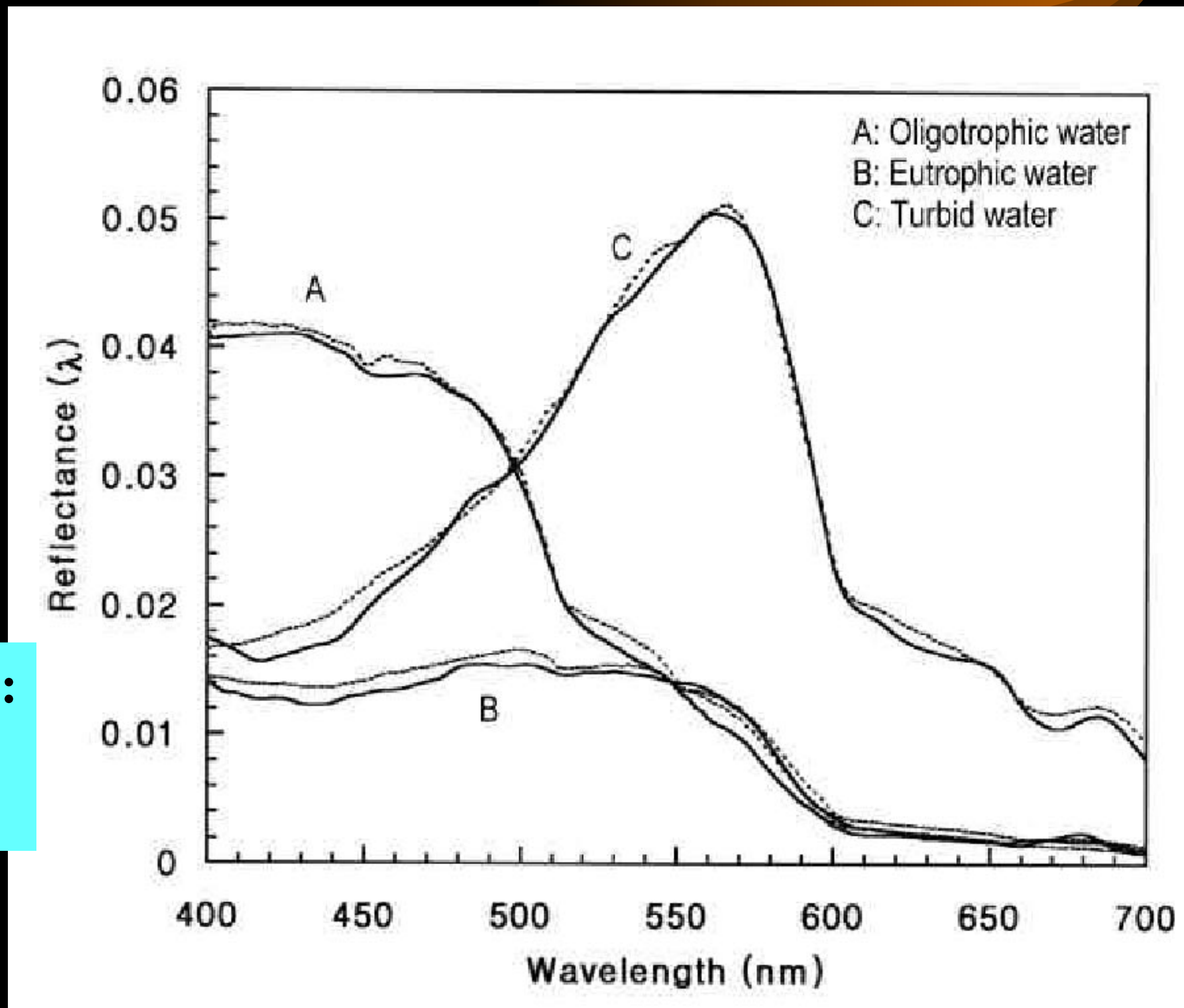
**Each stripe represents coverage during one orbit.**

# Visible light spectrum as viewed looking at sea surface

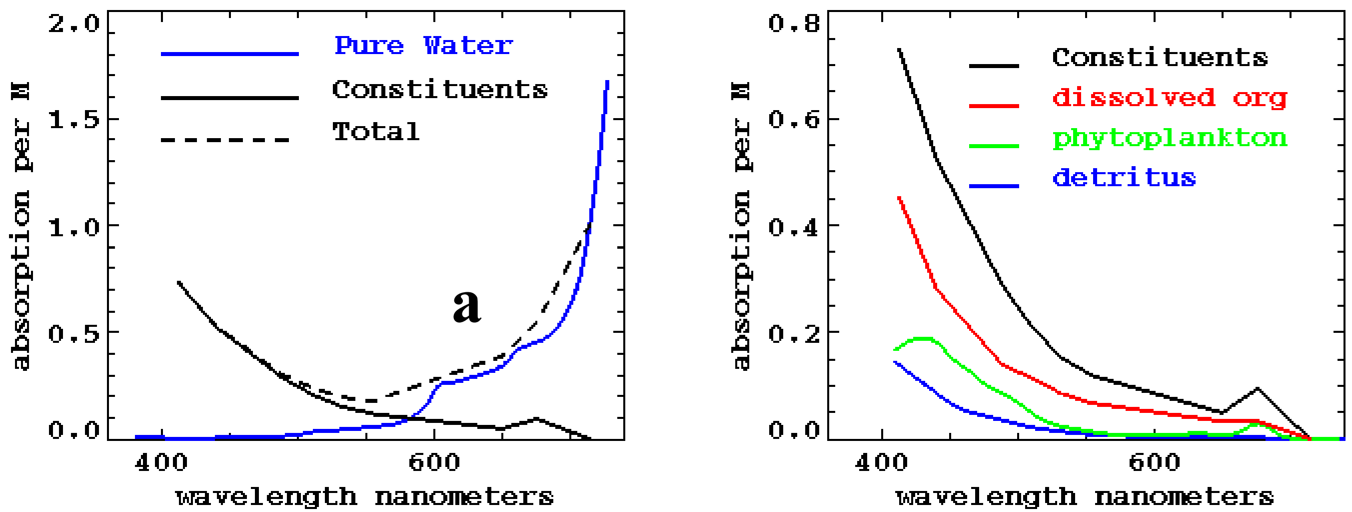
**How can we get water constituents from these spectra?**

$R_{rs} \sim b/a$

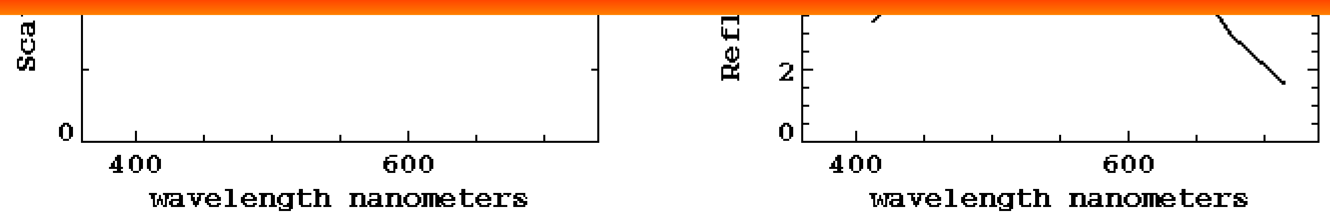
**Inherent optical properties:**
**b=optical scattering**
**a=optical absorption**



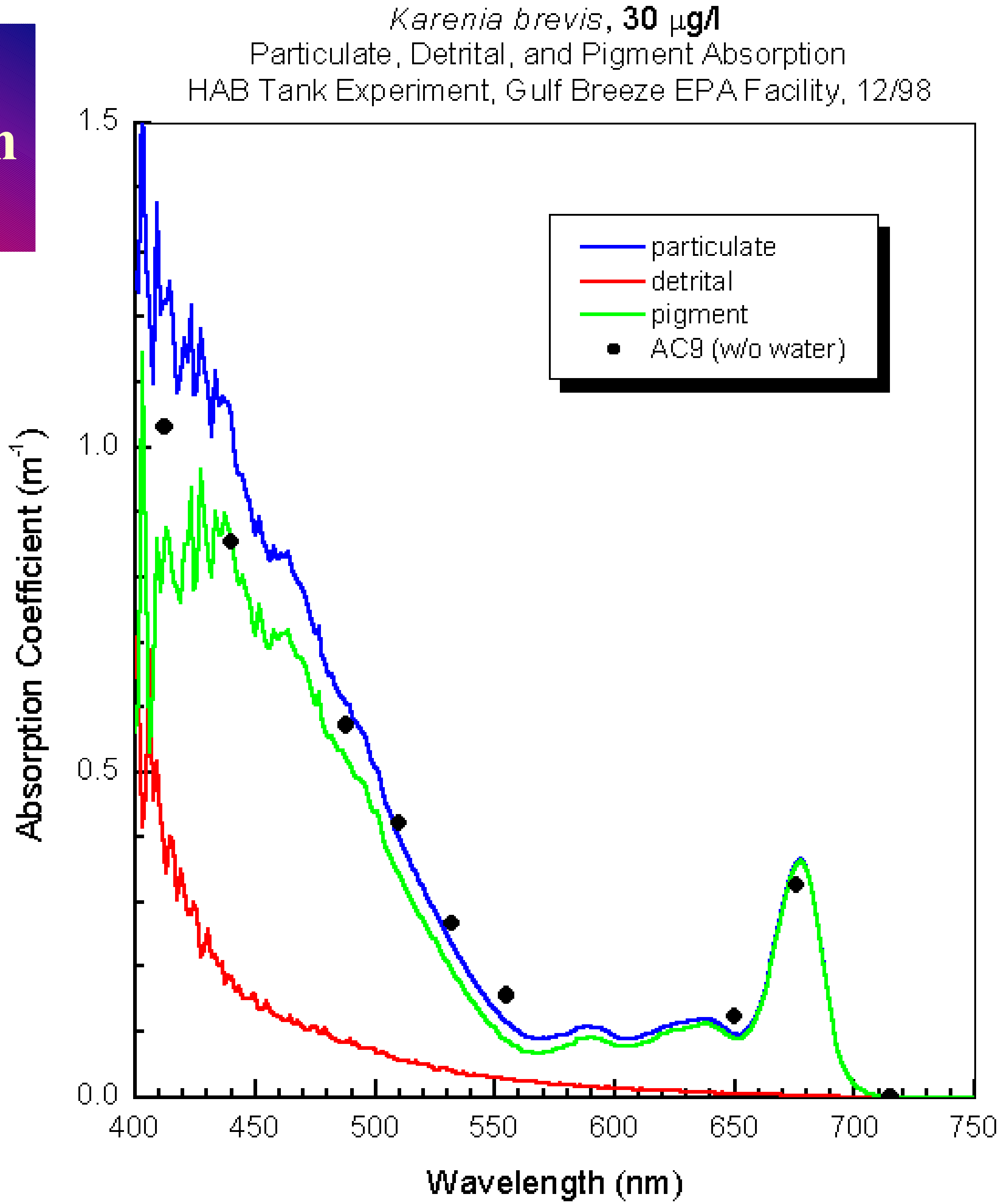
# Near-surface water from Mobile Bay outflow plume



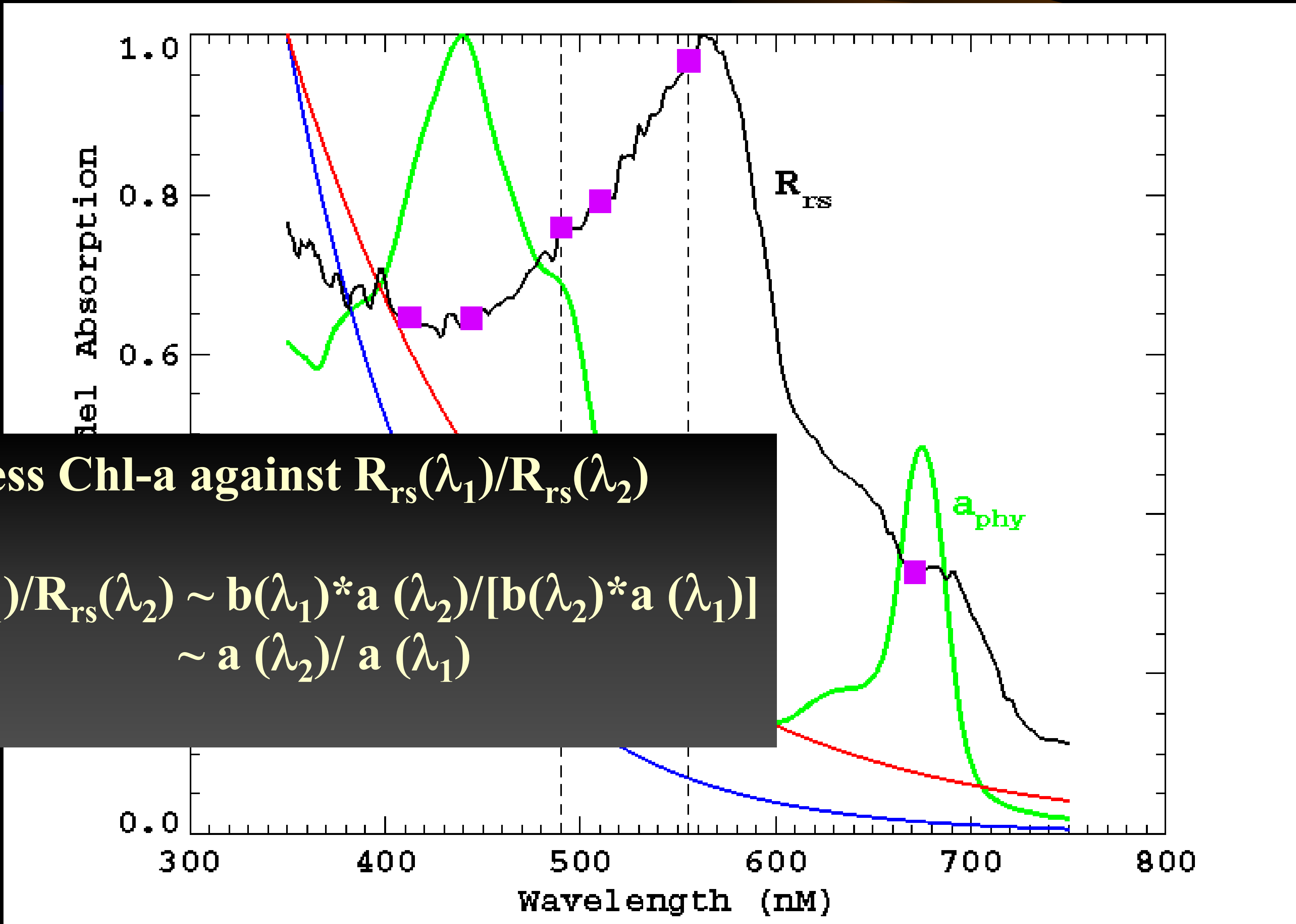

**We have gone from water constituents are really like to what the reflectance ought to look like from satellite. What we want is the reverse - take satellite reflectances and find water constituents.**



# One red tide population in a tank.



# Modeled absorption from phytoplankton, detritus & gelbstoff. Ocean surface reflectance - black line (includes pure water). Square symbols are at SeaWIFS bands.

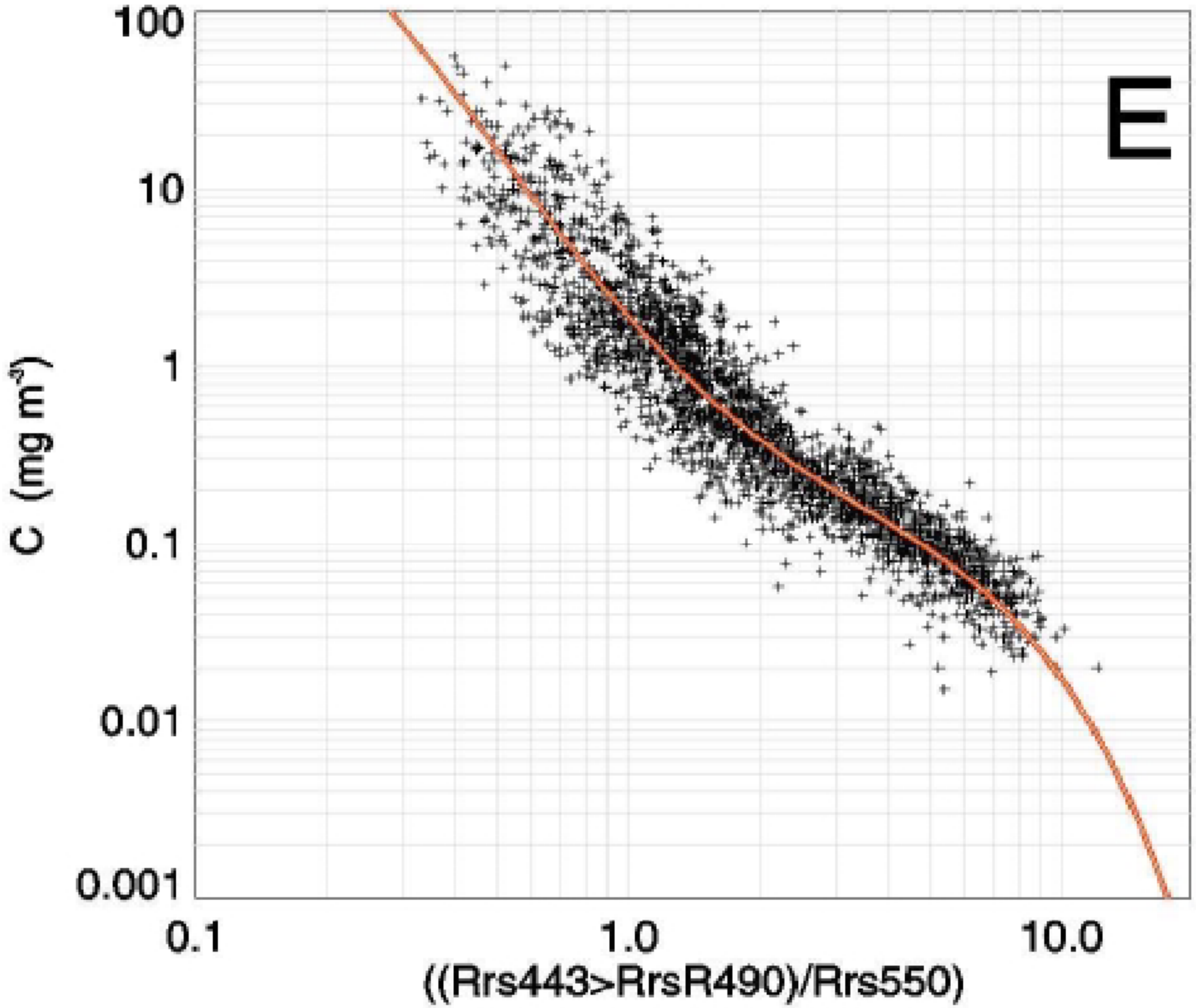



Regress Chl-a against $R_{rs}(\lambda_1)/R_{rs}(\lambda_2)$

$$R_{rs}(\lambda_1)/R_{rs}(\lambda_2) \sim b(\lambda_1)*a(\lambda_2)/[b(\lambda_2)*a(\lambda_1)]$$
$$\sim a(\lambda_2)/a(\lambda_1)$$

# "Global" fit of chl-a to ratio algorithm

The Chlor_a_2 algorithm was proposed by the developers of the SeaWiFS OC4.v4 algorithm (O'Reilly et al. 2000).
It was called OC3M (3 band, M for MODIS).



A plethora of algorithms!!!

Ok, it's not the best, but there are only 6 wavelengths!

We are actually doing pretty good while we wait for hyperspectral satellites.

and cdom correlate with chl-a, the ratios differ with season and geography.

EMPIRICAL ALGORITHMS

| ALGORITHM | RESULT | EQUATION(S) | Band Ratio (R), Coefficients(a) | REFERENCE | IDL Program |
|---|---|---|---|---|---|
| Global Processing (GPs) | [C+P] = | C13 = 10^(a0+ a1*R1)<br>C23 = 10^(a2+ a3*R2)<br>C13; IF C13 and C23 > 1.5ug/l Then [C+P]= C23 | R1 = Log(Lwn443/Lwn550)<br>R2 = Log(Lwn520/Lwn550)<br>a = [0.053 , -1.705, 0.522 , -2.440] | Evans and Gordon 1994 | a_gps_p |
| Clark 3-band (C3b) | [C+P] = | 10^(a0 + a1*R) | R = Log((Lwn443+Lwn520)/Lwn550)<br>a = [0.746, -2.252] | (Muller-Karger et al. 1990; D. Clark) McClain and Yeh, 1994 | a_c3b_p |
| Aiken 21+23 | C = | C_21 = EXP(a0 + a1*Ln(R))<br>C_23 = (R +a2)/(a3 + a4*R)<br>C_21; IF C < 2.0ug/l THEN C = C_23 | R = Lwn490/Lwn555<br>a = [0.464, -1.989, -5.29, 0.719, -4.23] | Aiken et al. Vol 29,1995 | a_a213_c |
| 22+24 | [C+P] = | C_22 = EXP(a0 + a1*Log(R))<br>C_24 = (R +a2)/(a3 + a4*R)<br>C_22; IF [C+P] < 2.0ug/l THEN [C+P] = C_24 | R = Lwn490/Lwn555<br>a = [0.696, -2.085, -5.29, 0.592, -3.48] | Aiken et al. Vol 29,1995 | a_a224_p |
| S_C | C = | 10^(a0 + a1*R) | R = Log((Lwn520 + Lwn565)/Lwn490)<br>a = [-0.55006, 3.497] | Science on the GLI Mission, p.16<br>Ocean Optics XIII, Halifax, Oct 96 | a_octs_c |
| S_P | [C+P] = | 10^(a0 + a1*R1 + a2*R2) | R1 = Log(Lwn443/Lwn520)<br>R2 = Log(Lwn490/Lwn520)<br>a = [0.19535, -2.079, -3.497] | Ocean Optics XIII, Halifax, Oct 96<br>Pers. Comm. to C. McClain | a_octs_p |
| | | | | | a_pold_c |
| | | | | | a_cal1_c |
| | | | | | a_cal2_c |
| | | | | | a_cal3_c |
| | | | | | a_cal4_c |
| | | | | | a_mor1_c |
| | | | | | a_mor2_c |
| | | | | | a_mor3_c |
| | | | | | a_mor3_c |

| | | | | | DL Program |
|---|---|---|---|---|---|
| | | | | | _oc1a_c |
| metric) | | | a = [0.3636,-2.350, -0.010] | | _oc1b_c |
| n Chlorophyll 1c<br>dratic Polynomial) | C = | 10^(a0 + a1*R + a2*R^2) | R = Log(Rrs490/Rrs555)<br>a = [0.3920, -2.8550, 0.6580] | This Chapter | a_oc1c_c |
| n Chlorophyll 1d<br>ic Polynomial) | C = | 10^(a0 + a1*R + a2*R^2 + a3*R^3) | R = Log(Rrs490/Rrs555)<br>a = [0.3335, -2.9164, 2.4686, -2.5195] | This Chapter | a_oc1d_c |
| n Chlorophyll 2<br>dified Cubic Polynomial) | C = | 10^(a0 + a1*R + a2*R^2 + a3*R^3) +a4 | R = Log(Rrs490/Rrs555)<br>a = [0.3410, -3.0010, 2.8110, -2.0410, -0.0400] | This Chapter | a_oc2_c |
| n Chlorophyll 2a<br>dified Cubic Polynomial) | C = | 10^(a0 + a1*R + a2*R^2 + a3*R^3) +a4 | R = Log(Rrs443/Rrs555)<br>a = [0.1909, -1.9961, 1.3020, -0.5091, -0.0815] | This Chapter | a_oc2a_c |
| n Chlorophyll 4<br>dified Cubic Polynomial) | C = | 10^(a0 + a1*R + a2*R^2 + a3*R^3) +a4 | R = Log((Rrs443>Rrs490>Rrs510)/Rrs555)<br>a = [ 0.4708, -3.8469, 4.5338, -2.4434, -0.0414] | This Chapter | a_oc4_c |
| n Pigment 2a<br>(Modified Cubic Polynomial) | P = | 10^(a0 + a1*R + a2*R^2 + a3*R^3) +a4 | R = Log(Rrs490/Rrs555)<br>a = [0.5880, -3.1422, 2.7334, -1.7960, -0.07] | This Chapter | a_op2a_p |
| Ocean Pigment 2<br>(Modified Cubic Polynomial) | C =<br>P = | 10^(a0 + a1*R + a2*R^2 + a3*R^3) +a4<br>1.3403*C^0.9829 | R = Log(Rrs490/Rrs555)<br>a = [0.3410, -3.0010, 2.8110, -2.0410, -0.0400] | This Chapter | a_oc2_c |

# *Getting GOM satellite stuff off the internet.*

**http://fermi.jhuapl.edu/avhrr/gm/averages/index.html**
**http://coastal.er.usgs.gov/east_gulf/**
**http://imars.usf.edu/**
**http://www.esl.lsu.edu/**
**http://www-ccar.colorado.edu/~leben/**

# *Satellite Technology and Fisheries in the Northern Gulf of Mexico*

**II. Application of Satellite Technology to some Fishery Issues.**

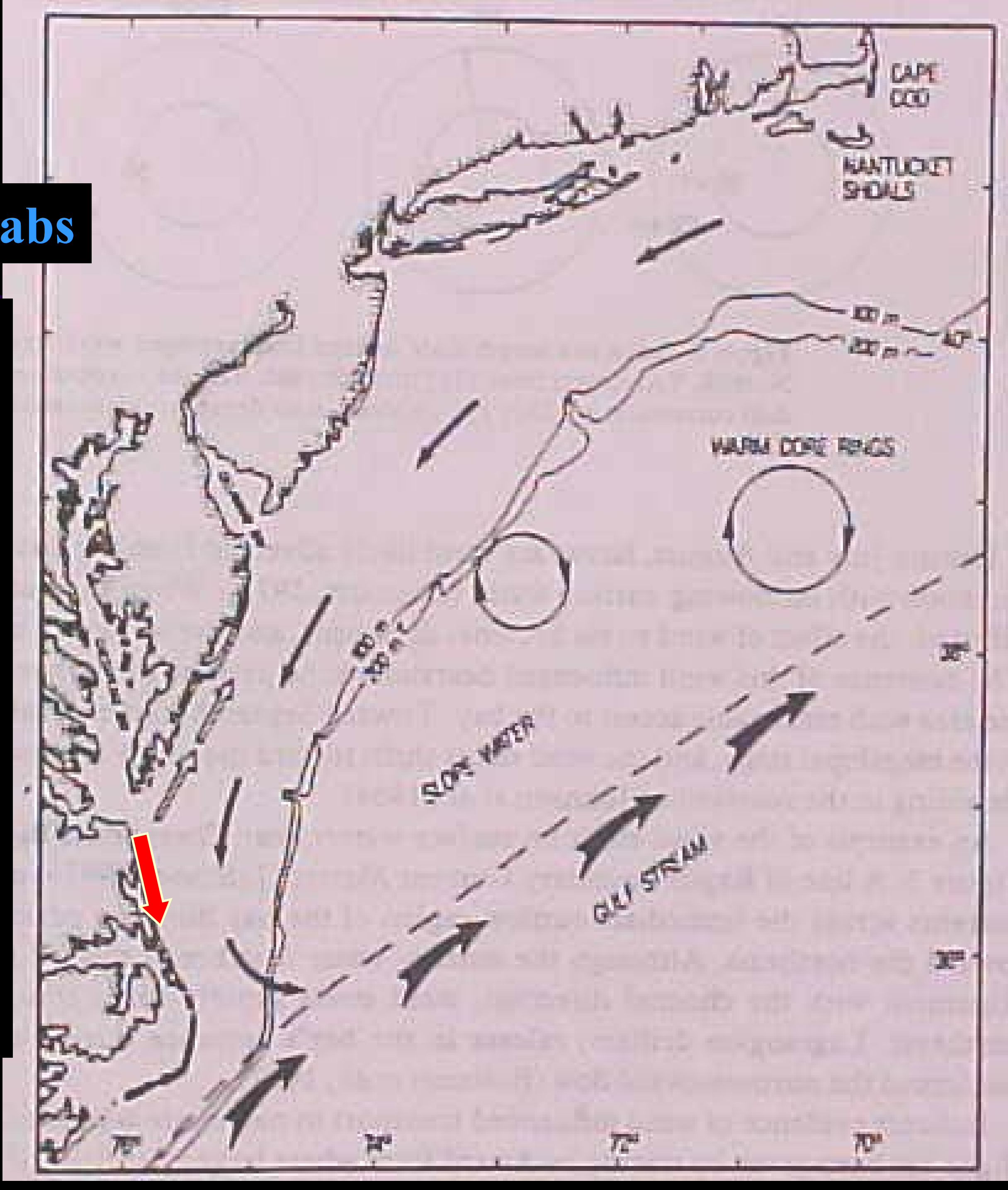
- **A. Recruitment - blue crabs**
- **B. Invasive and non-indigenous species - jellyfish**

# *Setting the stage*:

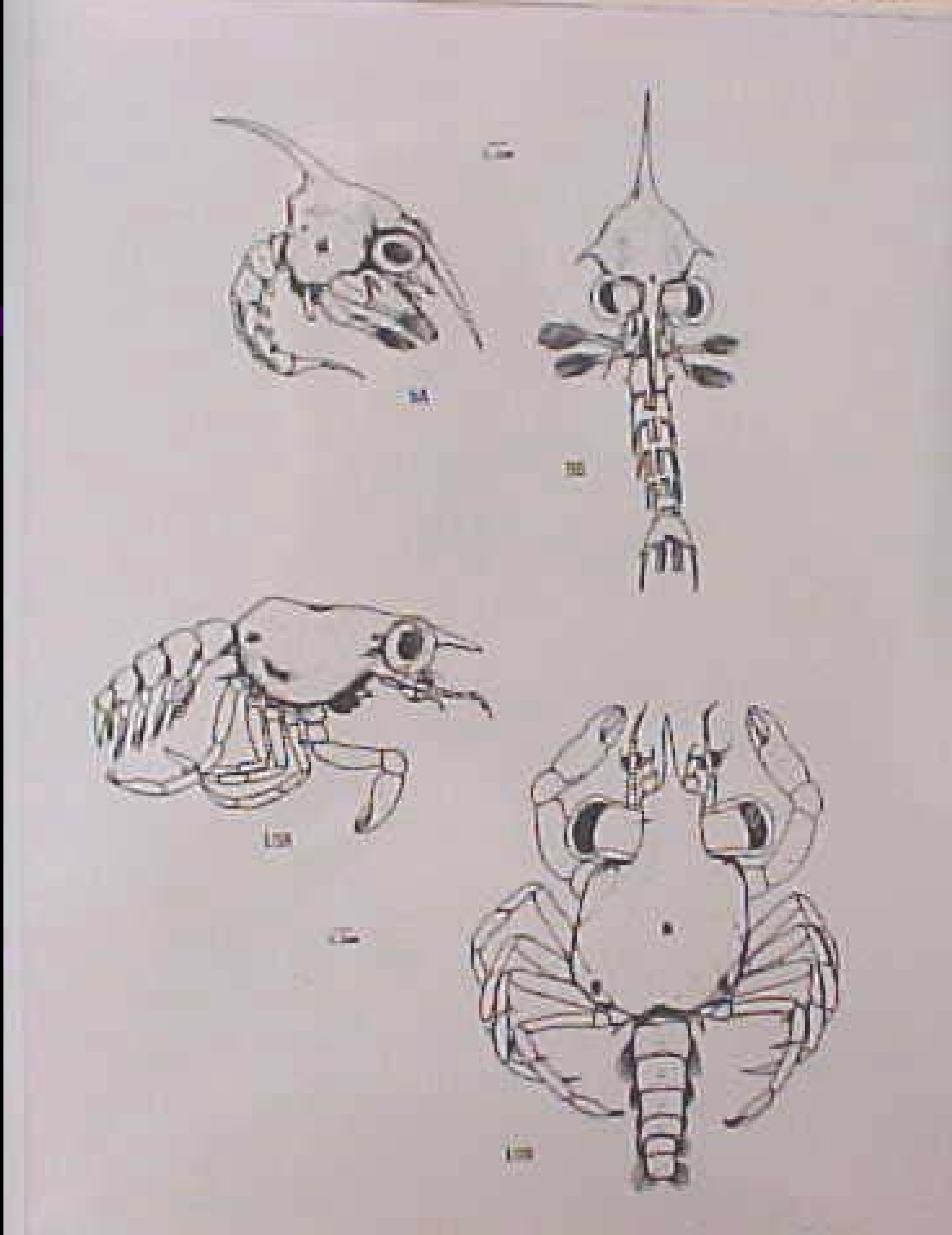
## Chesapeake Bay Blue Crabs

During June/July females spawn at the entrance to Chesapeake Bay on an ebbing tide. The buoyant larvae are dispersed to sea where they spend the next 30-50 days under the influence of the wind driven surface currents.

In Jun-Aug, winds to north keeping larvae in place. In September, winds reverse, driving megalopae back to Bay.

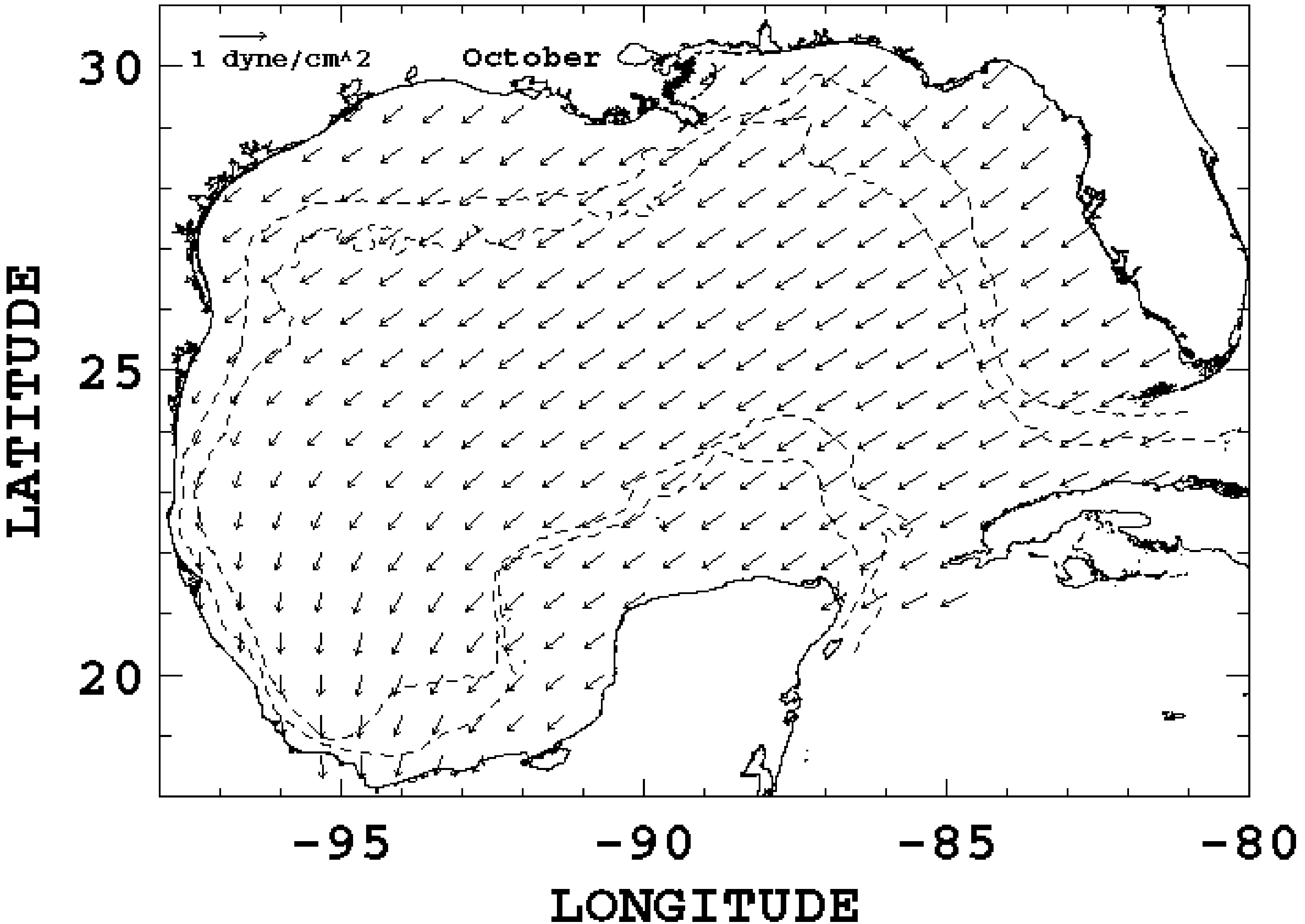


# Blue crab larvae at different life stages.



Currents on the continental shelf are driven by

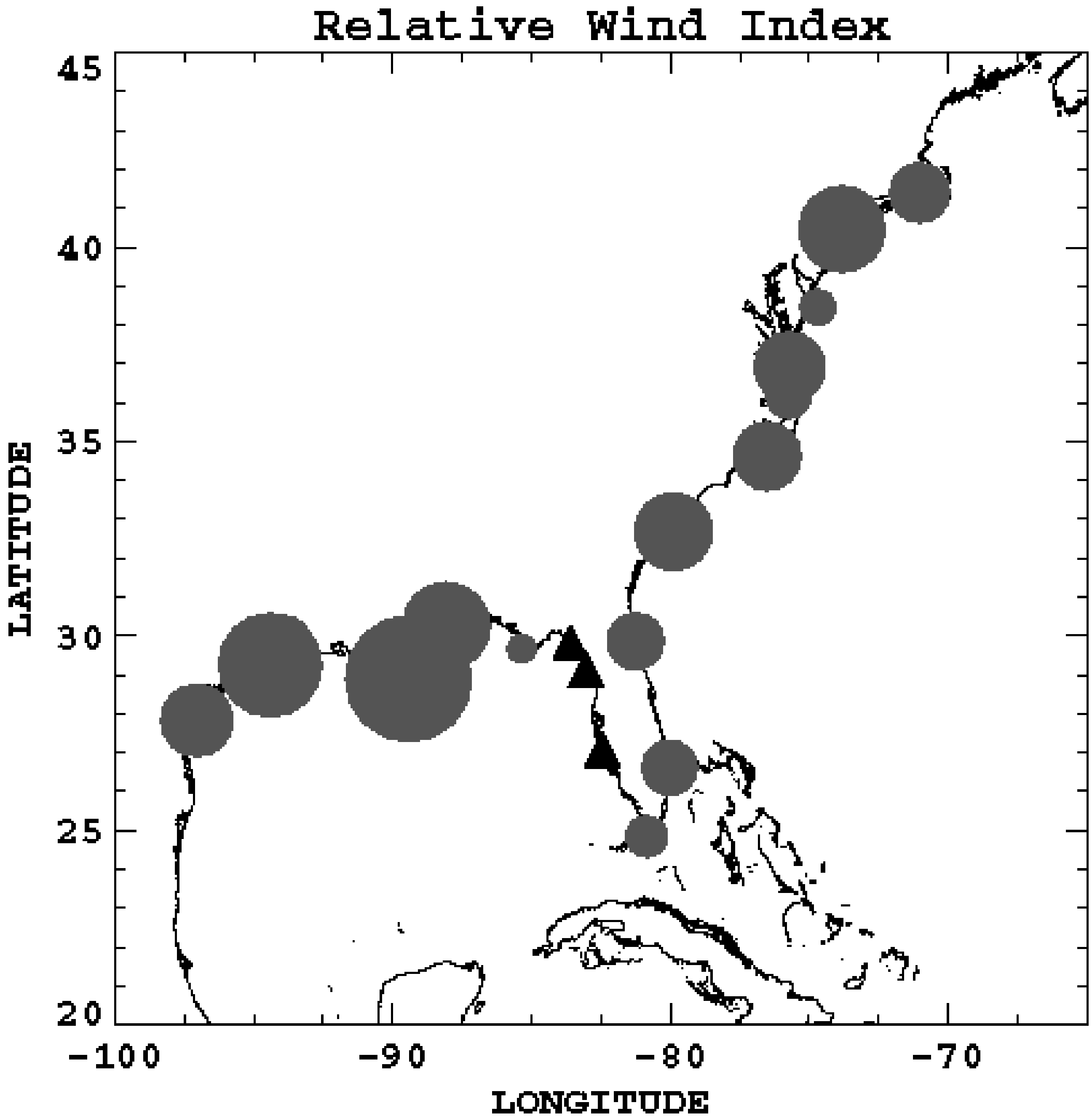
* winds
* deep basin 'events' which affect the shelf.


1 dyne/cm^2
October
30
25
20
-95
-90
-85
-80
LATITUDE
LONGITUDE

**Summer-Fall wind index from NDBC wind stations.**

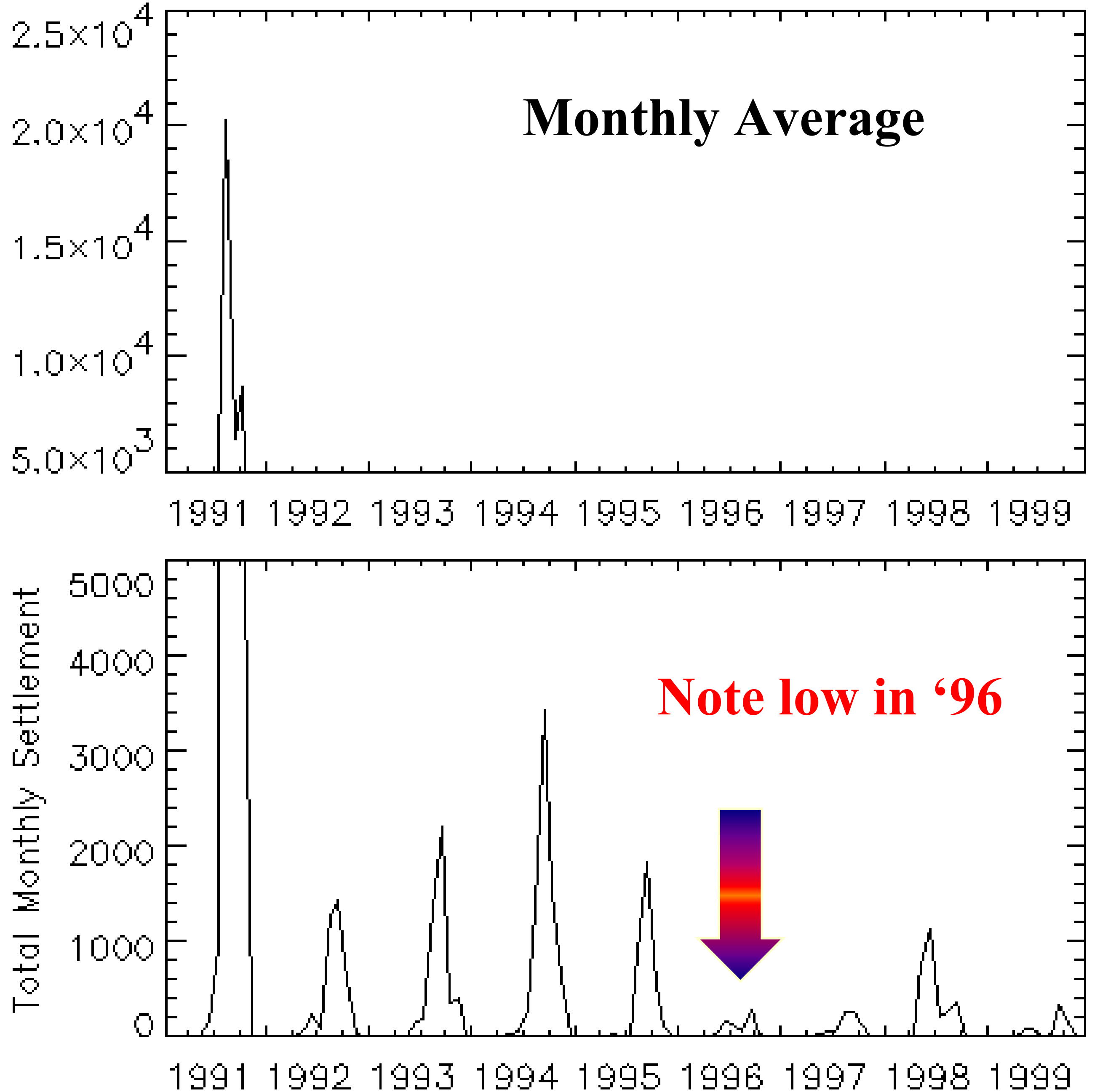
**South of 35N: Jul+Aug-Sep-Oct**

**North of 35N: Jun+Jul+Aug-Sep**



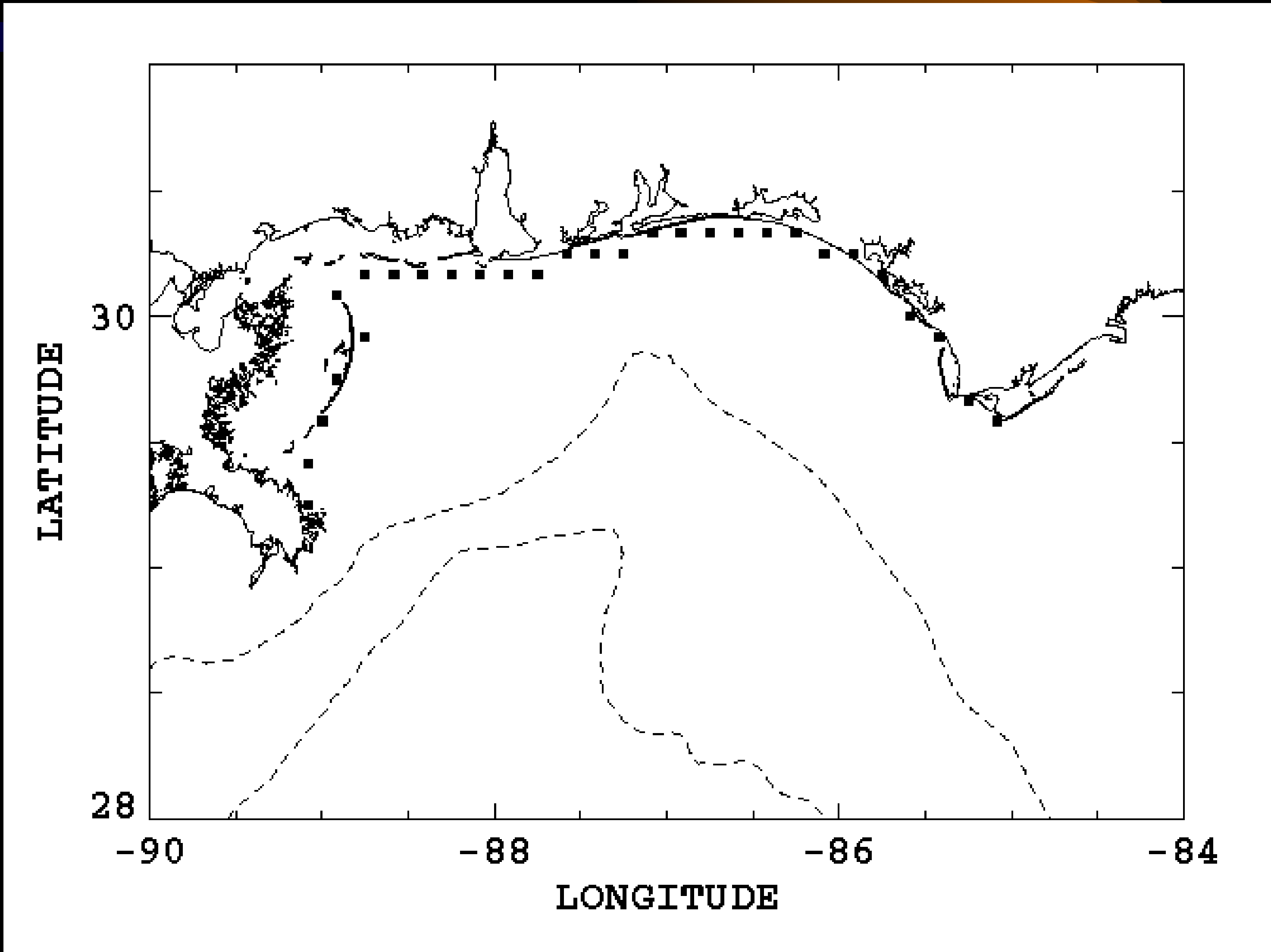
# Pictures of ac-filters and sampling techniques

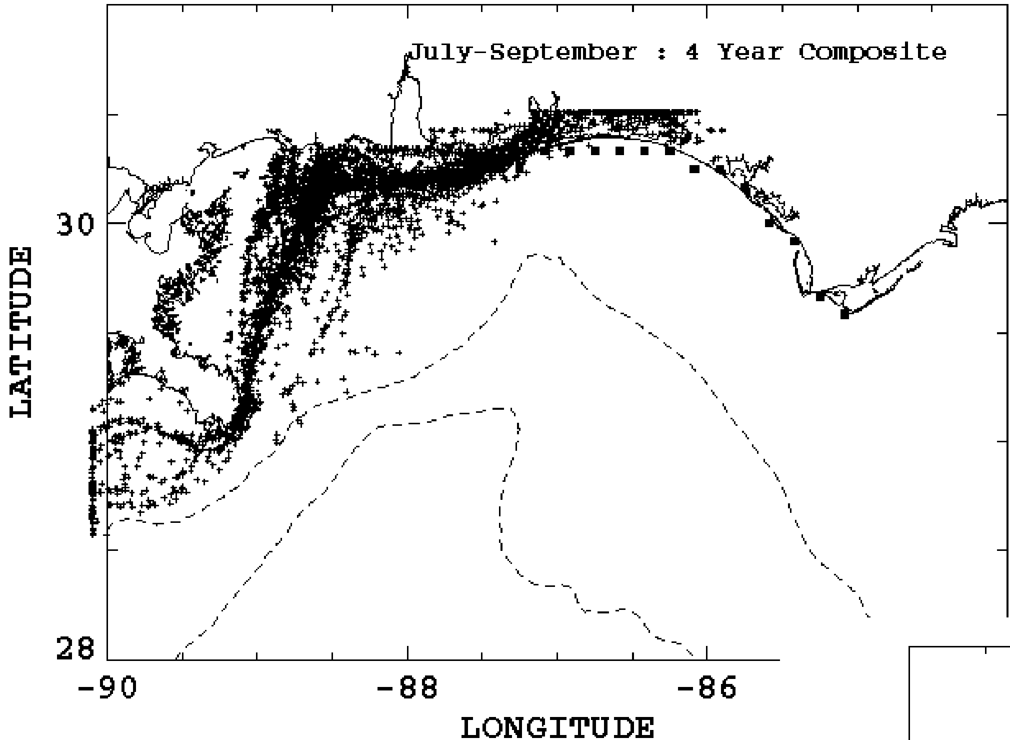
# Megalopae Settlement

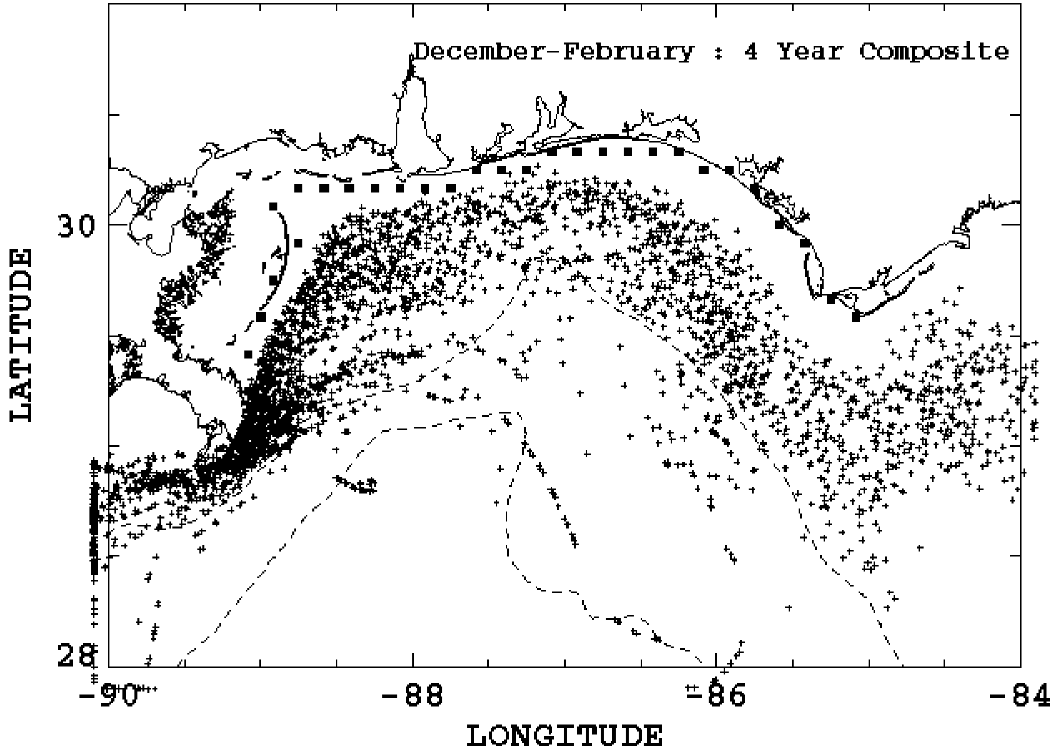


**Movie Loop**

Model crab larvae released at 10 day intervals at each point and integrated forward with model currents. After 30-50 days,are they close enough to shore to survive?



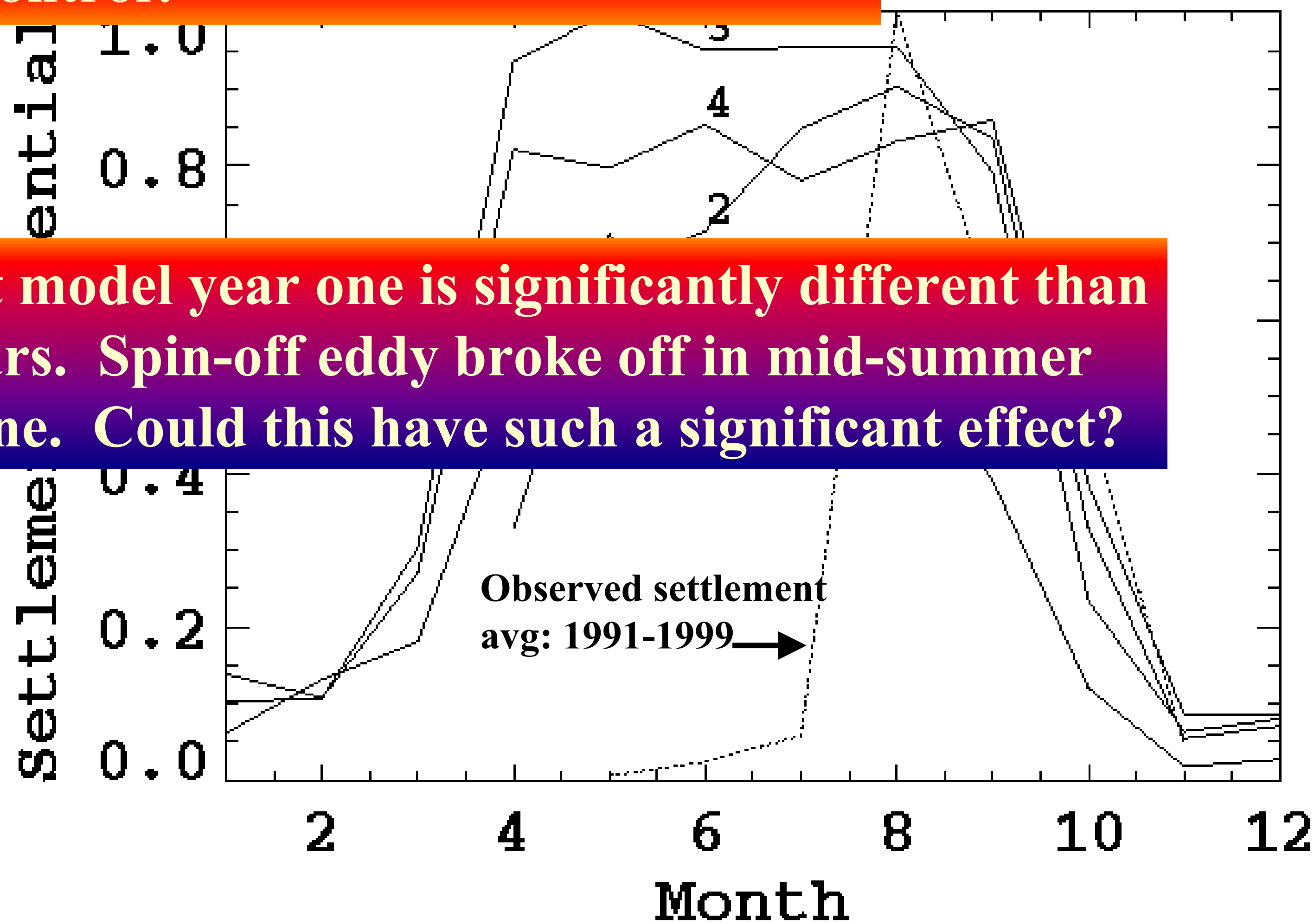



**Any crab larval point within 10 km of coast is considered 'successful.'**

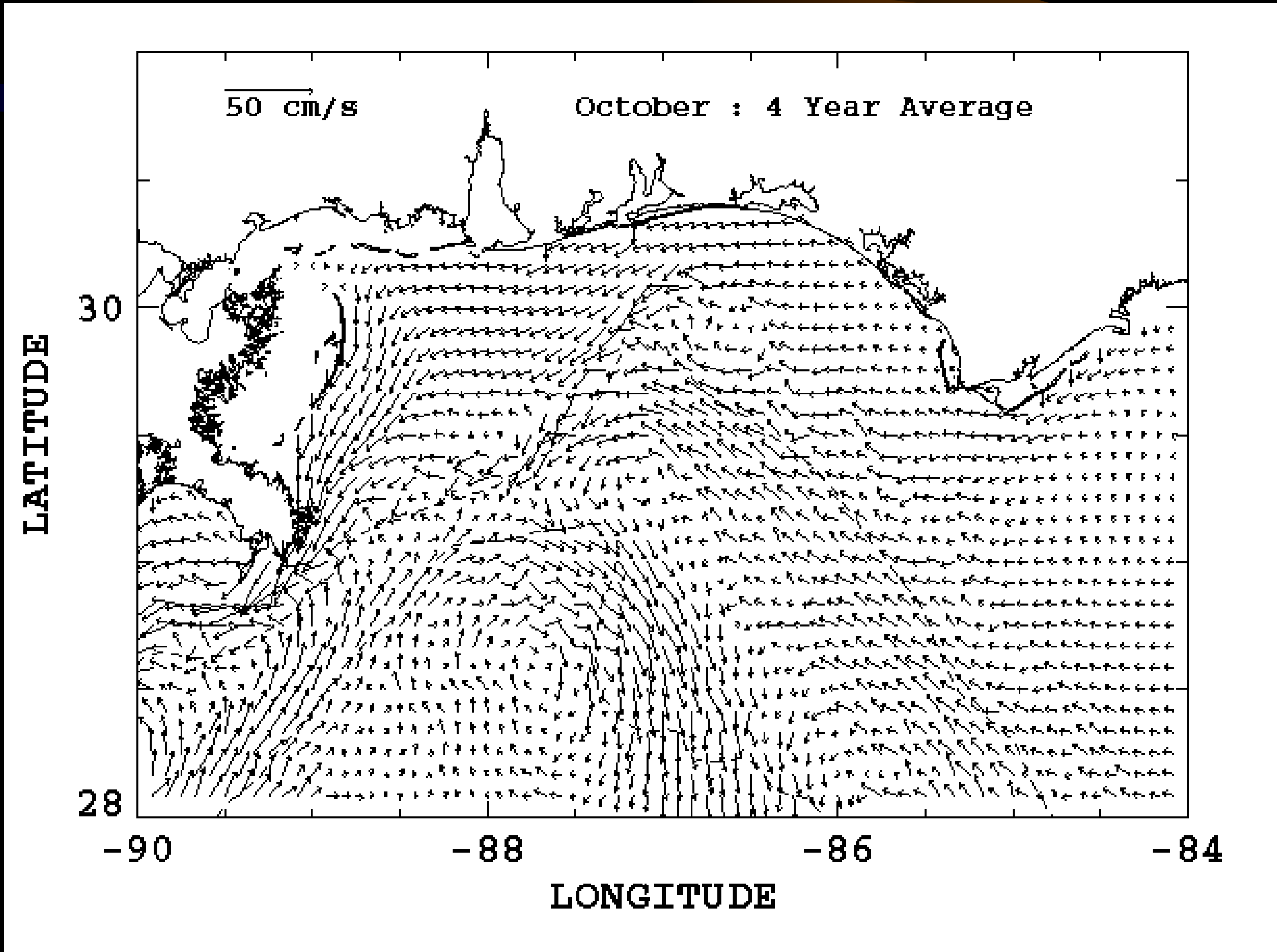
Settlement potential: Window of opportunity. Note actual settlement occurs within this window but starts much later - temperature control? Actual settlement stops at end of window - wind/current control?

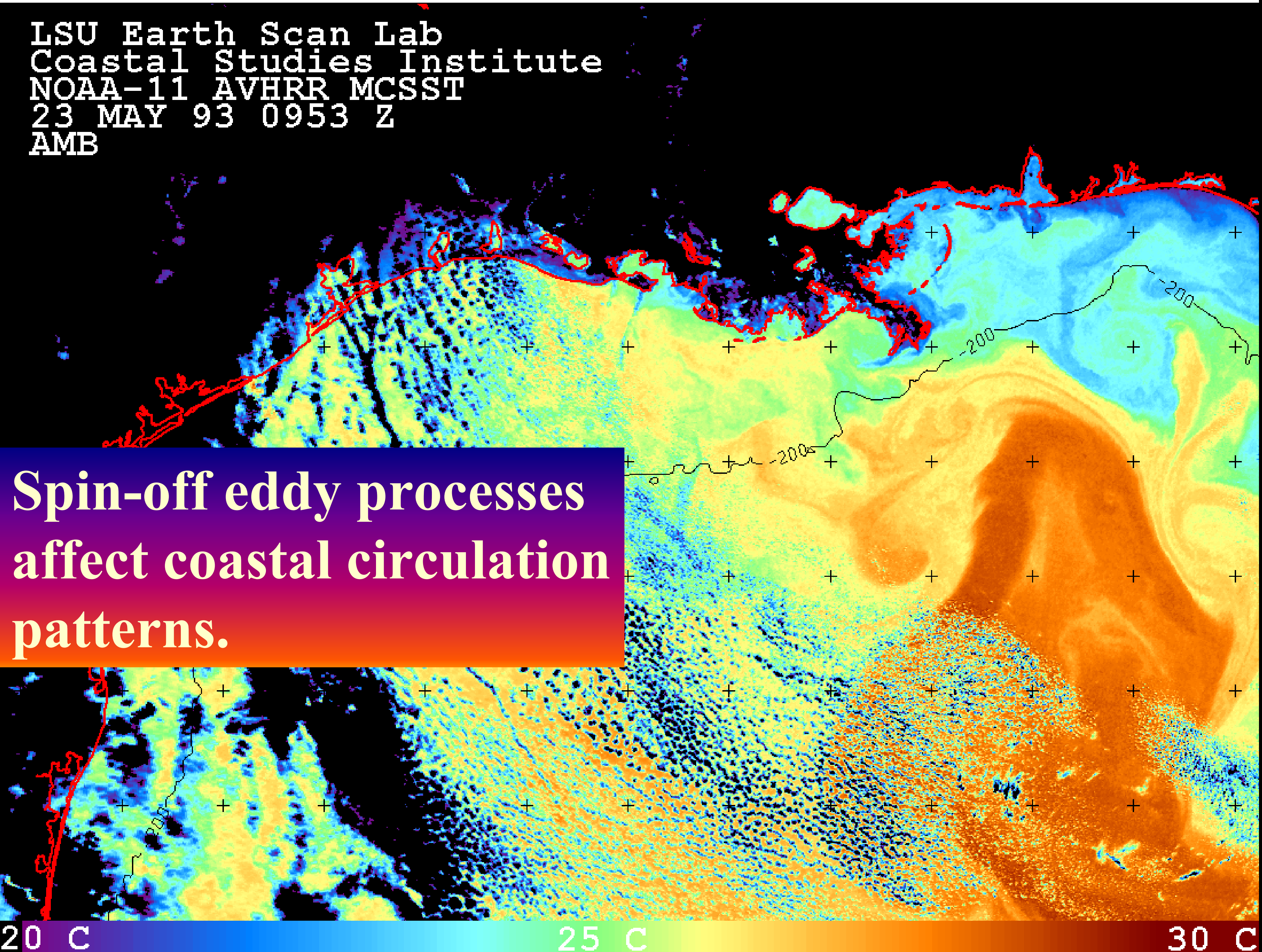
onth for 4 years



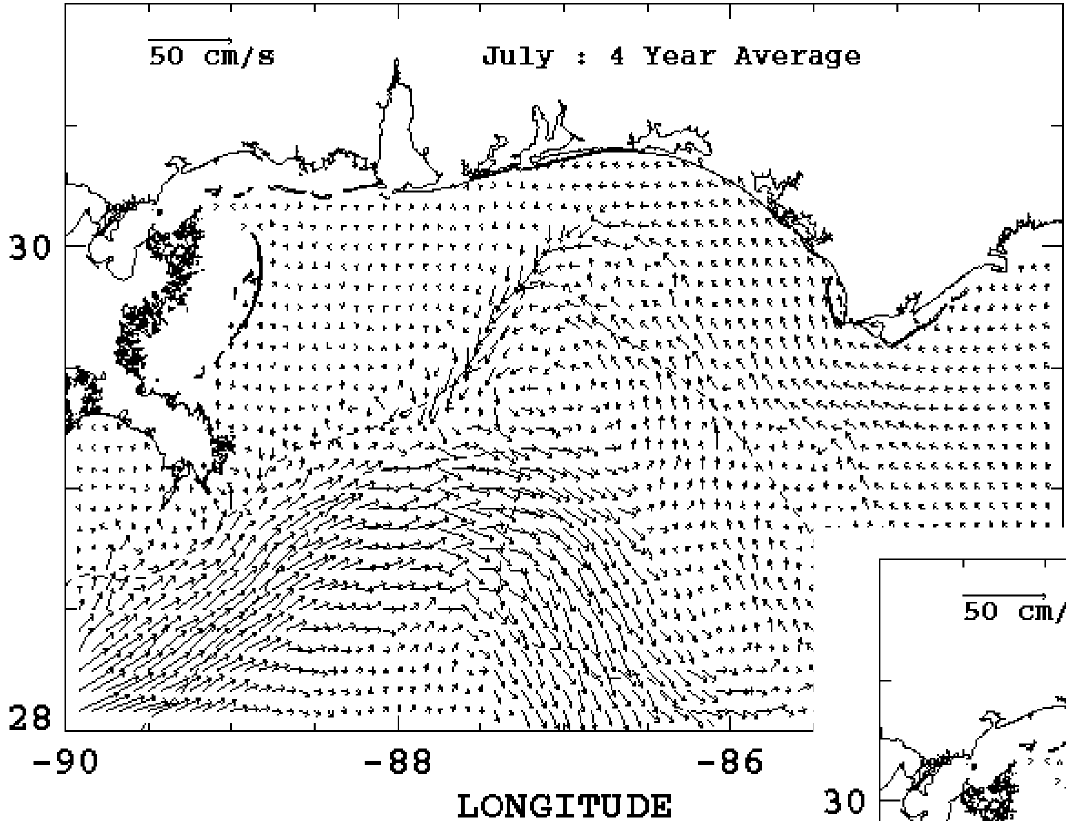

Note that model year one is significantly different than other years. Spin-off eddy broke off in mid-summer in year one. Could this have such a significant effect?

# October winds set the end of yearly recruitment period with offshore flow components.



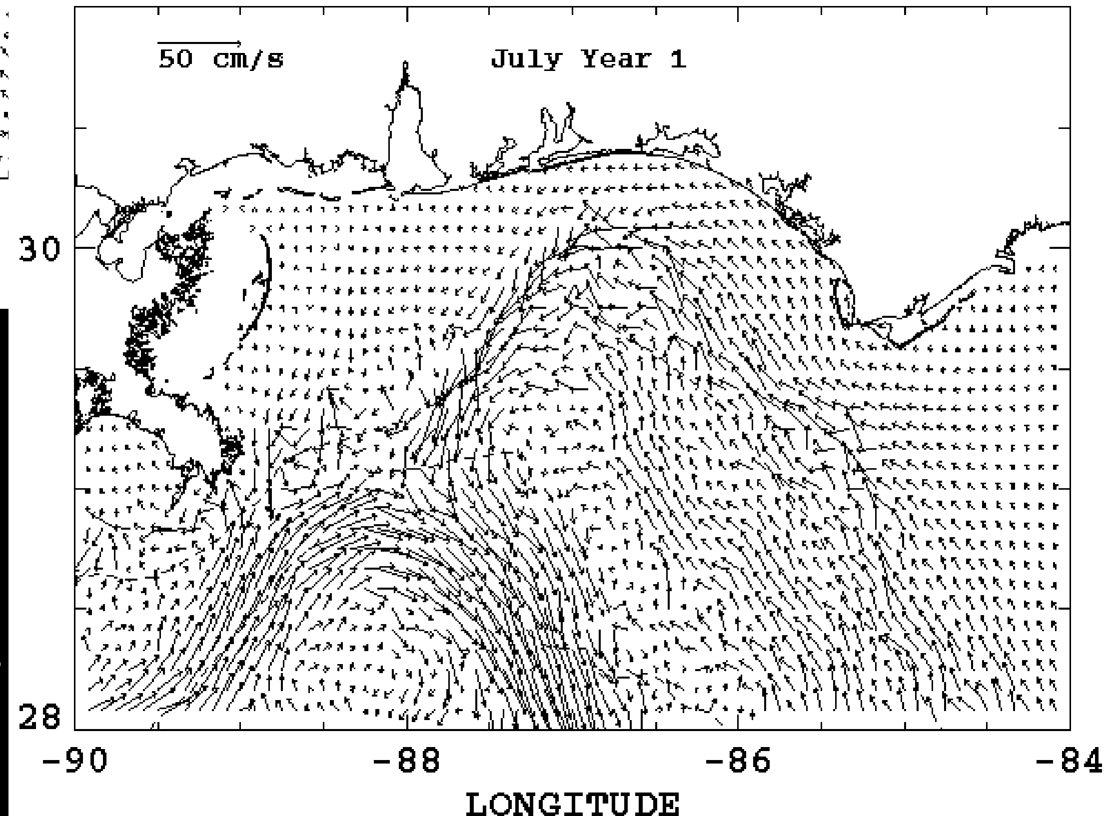



**Spin-off eddy processes affect coastal circulation patterns.**

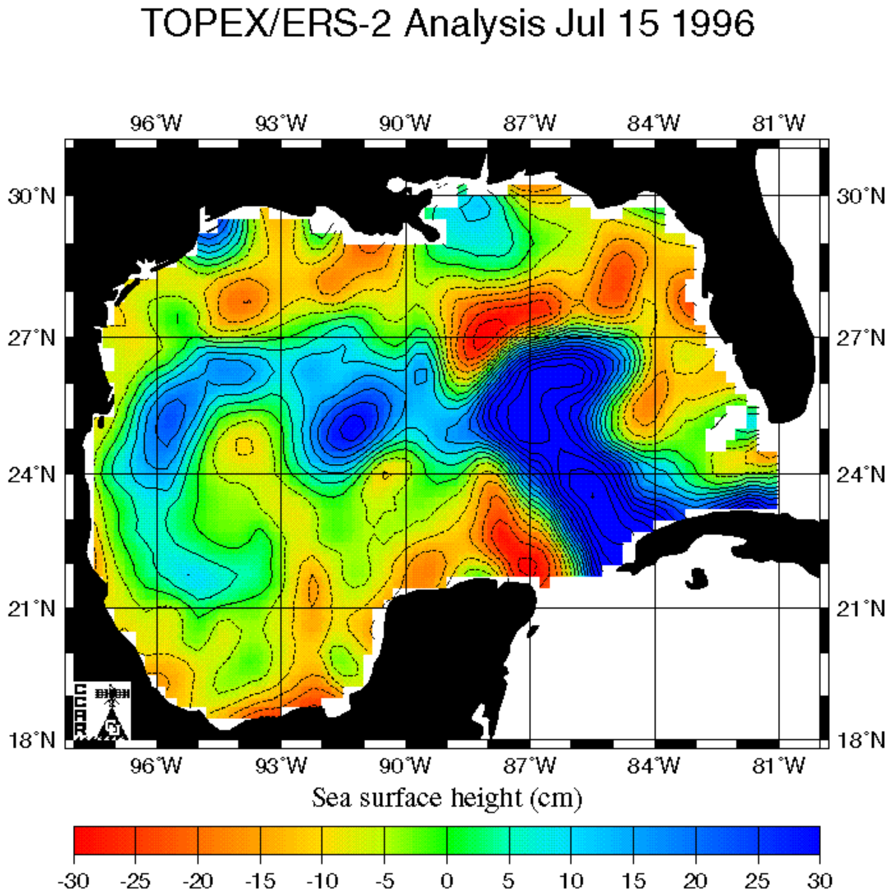


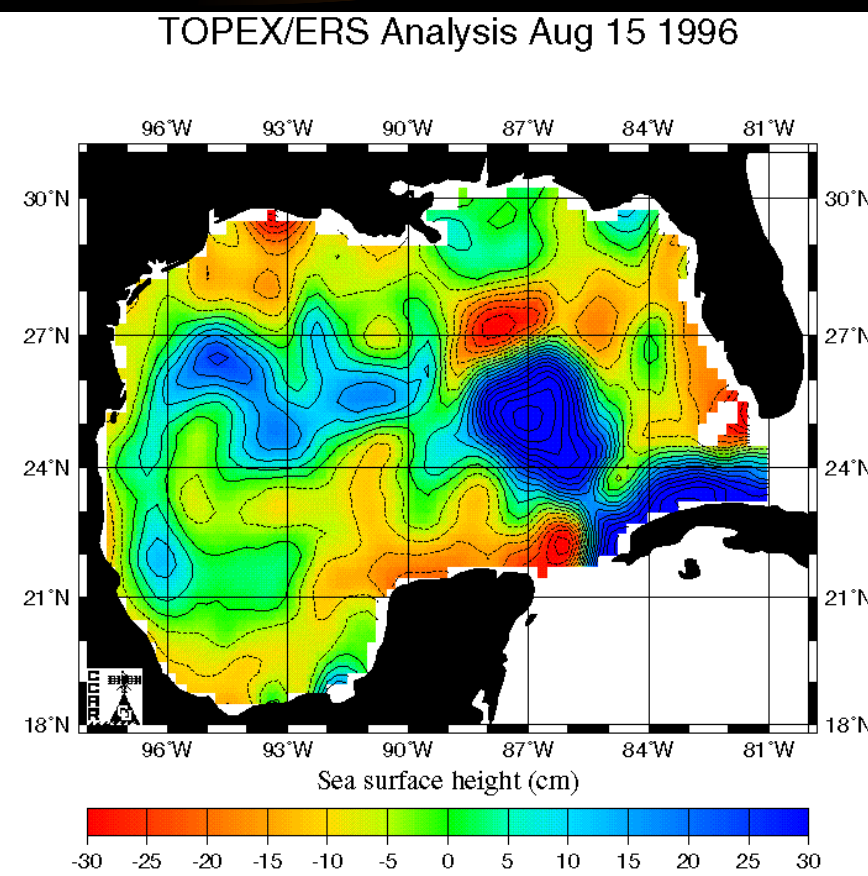

**July 4-year average shows very weak currents in western part of Bight**

**July Year 1, Loop Current eddy spin-off occurs. Slope front is broken up and currents stream out of Bight. Larvae will be lost.**



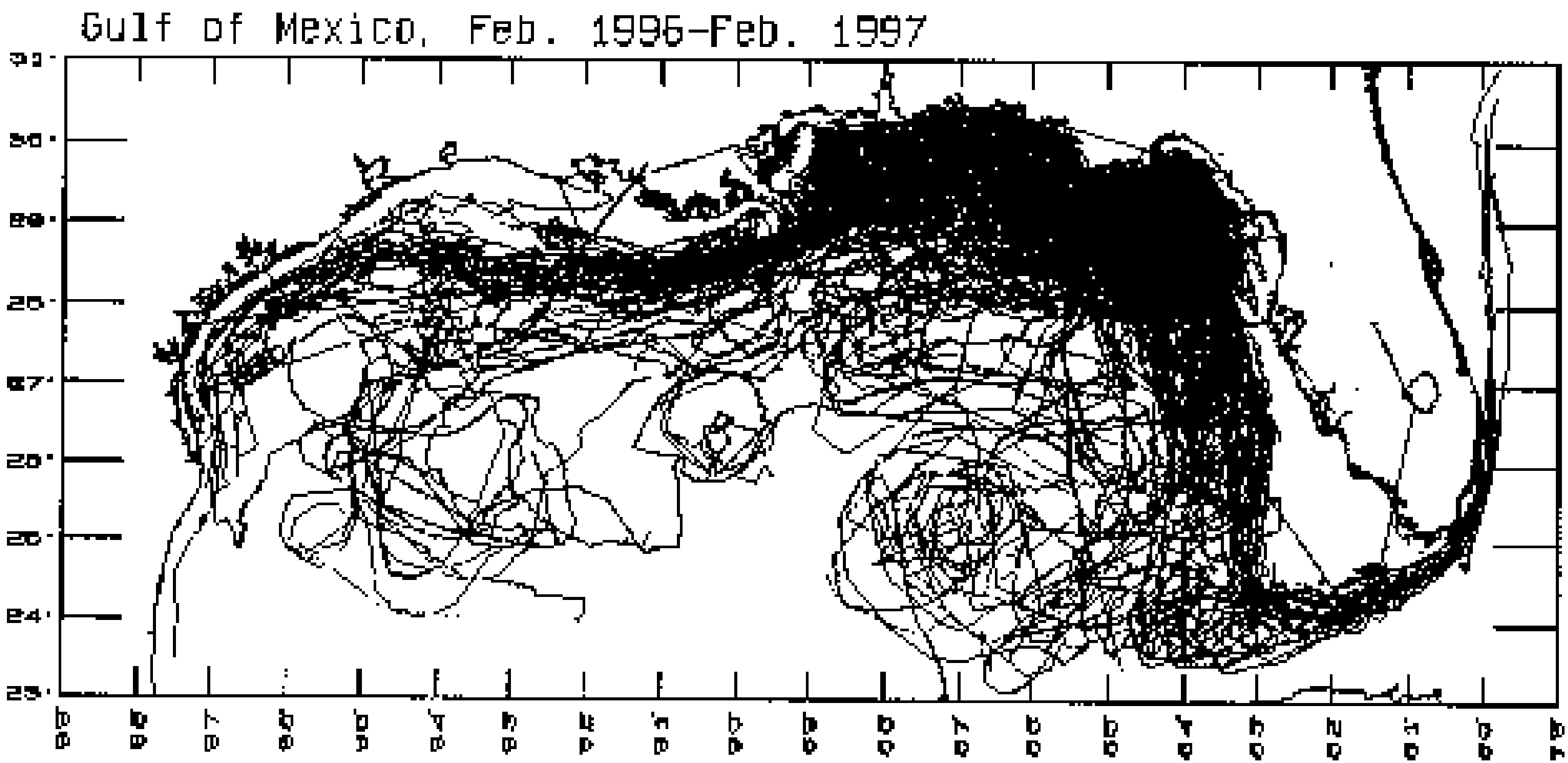
Recall that 1996 was year of very low recruitment.



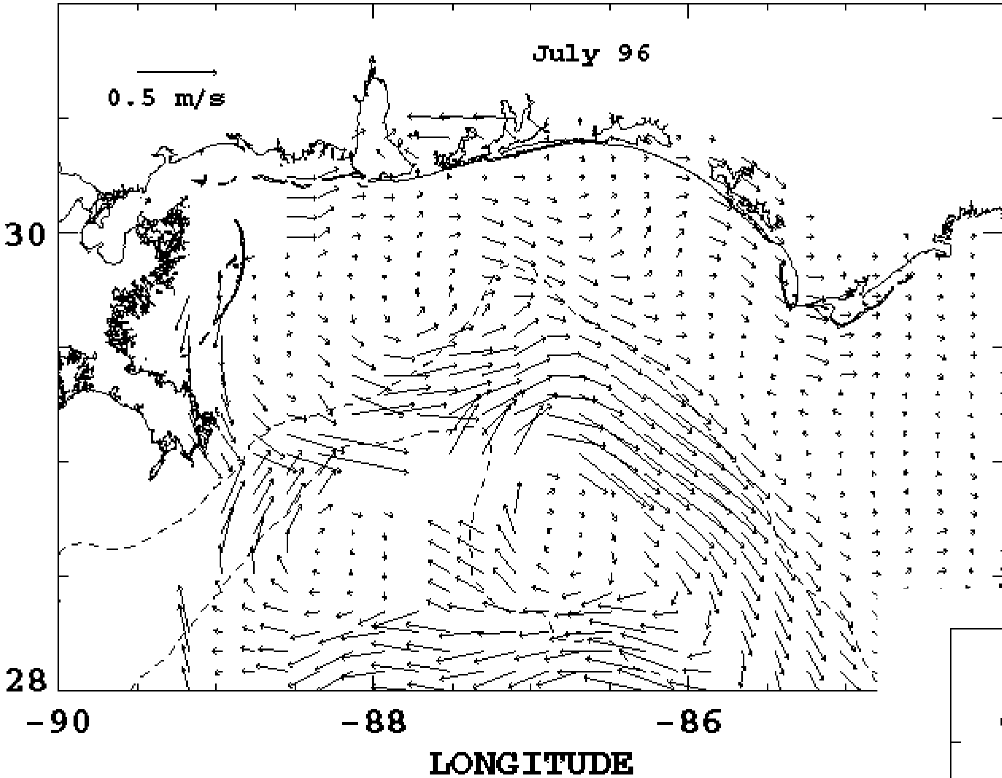




Satellite altimetry shows spin-off eddy forming in late July/early August, 1996.

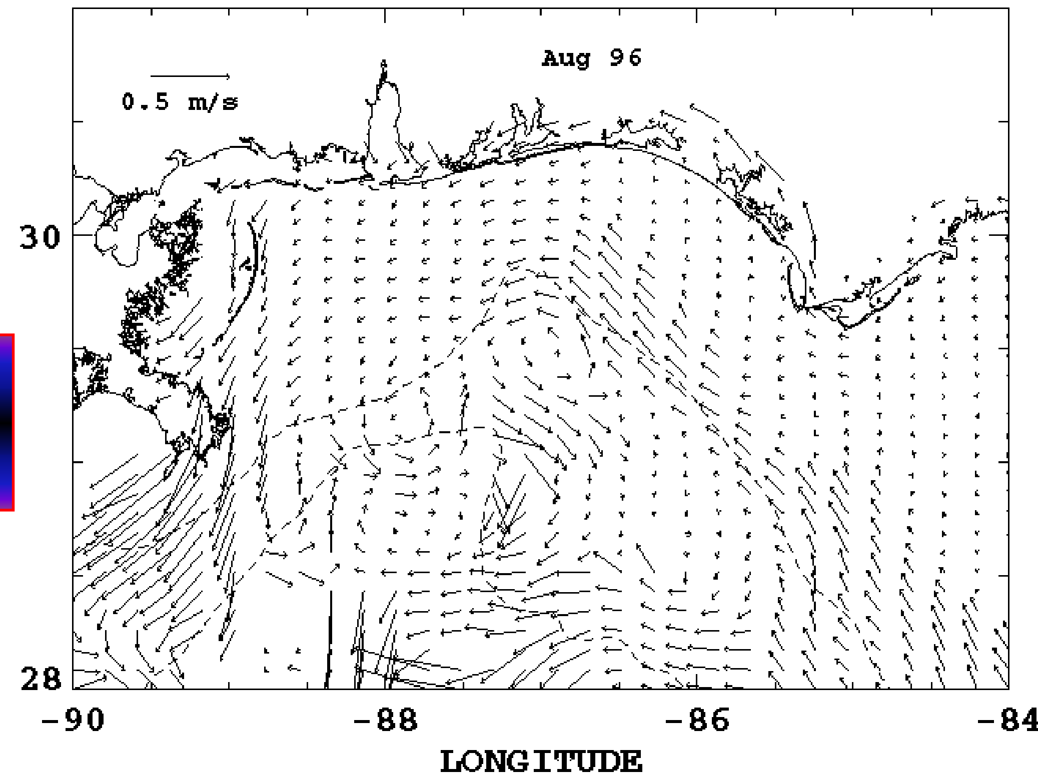
# Satellite tracked drifters from MMS experiment. Yang et al., 1999



Average of currents from satellite-tracked drifters.




July: eastward flow nearshore & eastward slope current offshore.



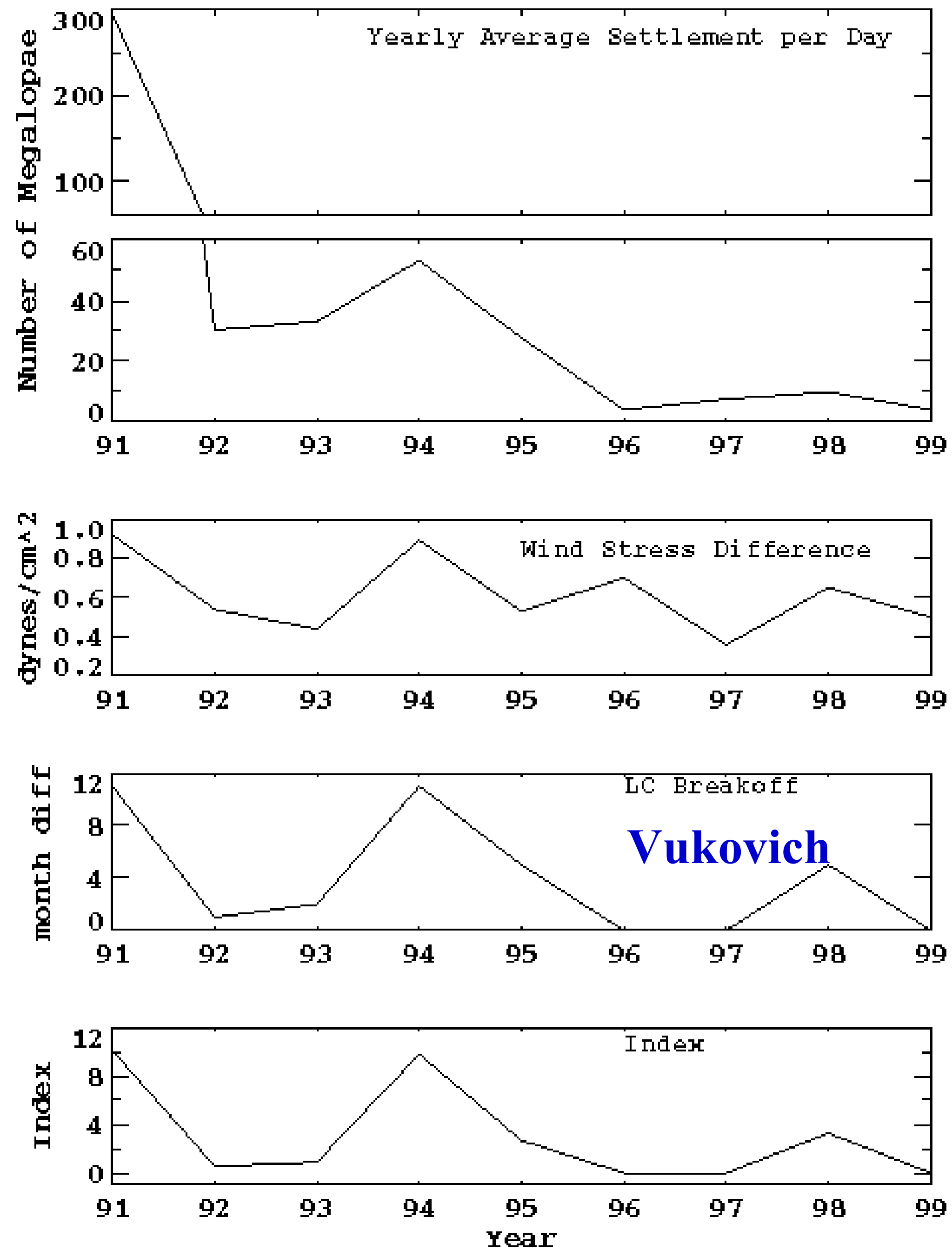

August: streaming west out of Bight.

Total yearly settlement

East wind stress:
July+Aug-Sep-Oct

Months before August
when break off occurred.

Index = wind*LC breakoff



**What have we learned?**

**1. Large scale circulation phenomena can significantly affect estuarine based fisheries.**

**2. Large scale phenomena can be tracked via satellite imagery and altimetry using the internet.**

**3. Wind data can also be downloaded from NDBC buoys via internet.**

# *The Loop Current and non-endemic species.*

**In which we learn that non-endemic species can be transported into the GOM and left on the shelf and in estuaries.**

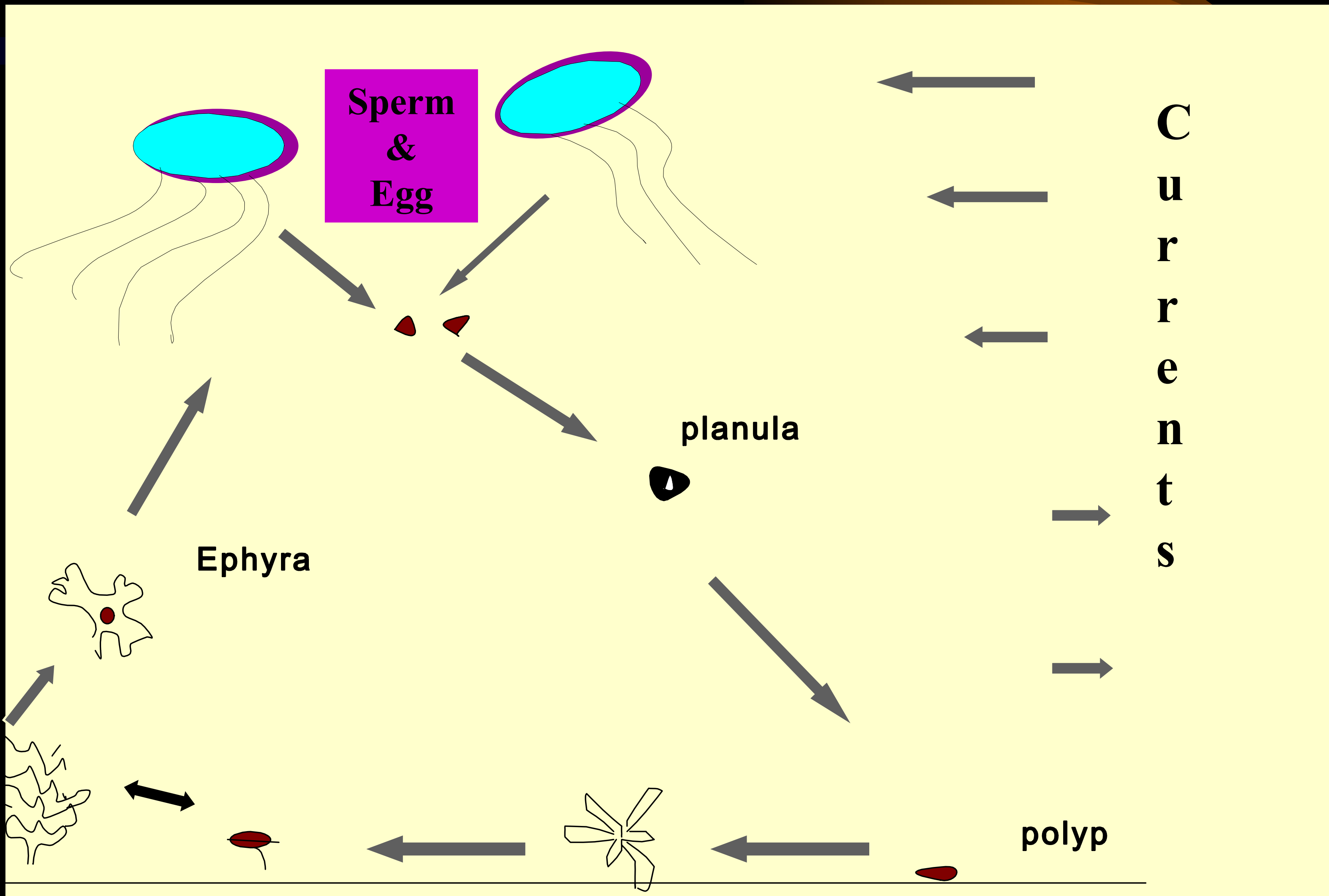
# Jellyfish invasion of 2000.


# Aircraft view of band of jellies

**Fisheries related problems:**

1. Fouling shrimp nets
2. Eating everything in sight.

# Reproductive Strategy of Jellyfish



Time-Line of invasion:

Mid-Late May, 2000: large amounts of Sargassum weed and blue water reported on the Mississippi Bight indicating presence of Atlantic/Caribbean Water.

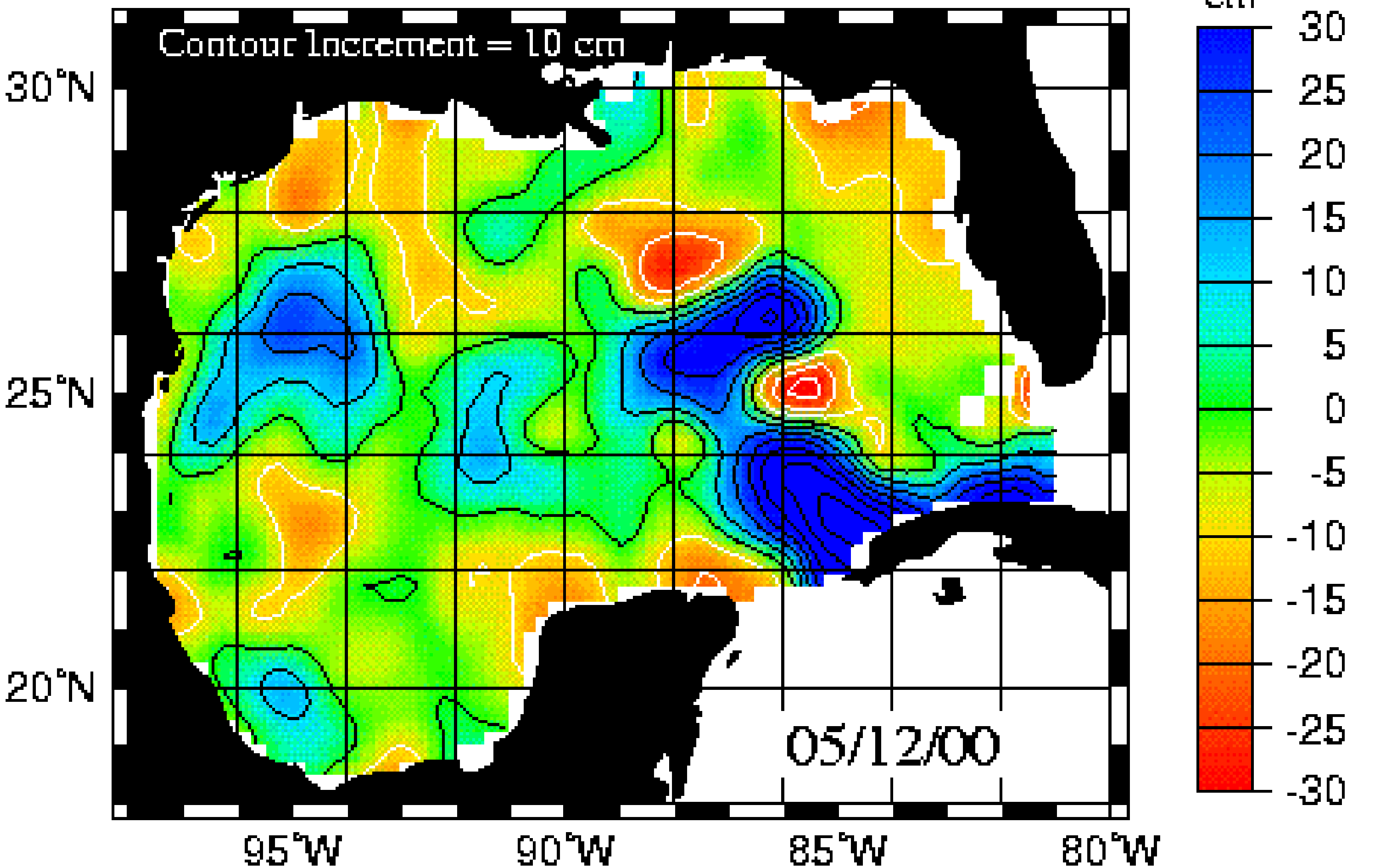
Early June: First specimen of ***Phyllorhiza*** found just offshore of Mobile Bay.

Late June - August: Fouling of shrimp trawls by large numbers of ***Phyllorhiza***.

**Looking for deep basin water flux onto Mississippi Bight shelf in late April-early May.**

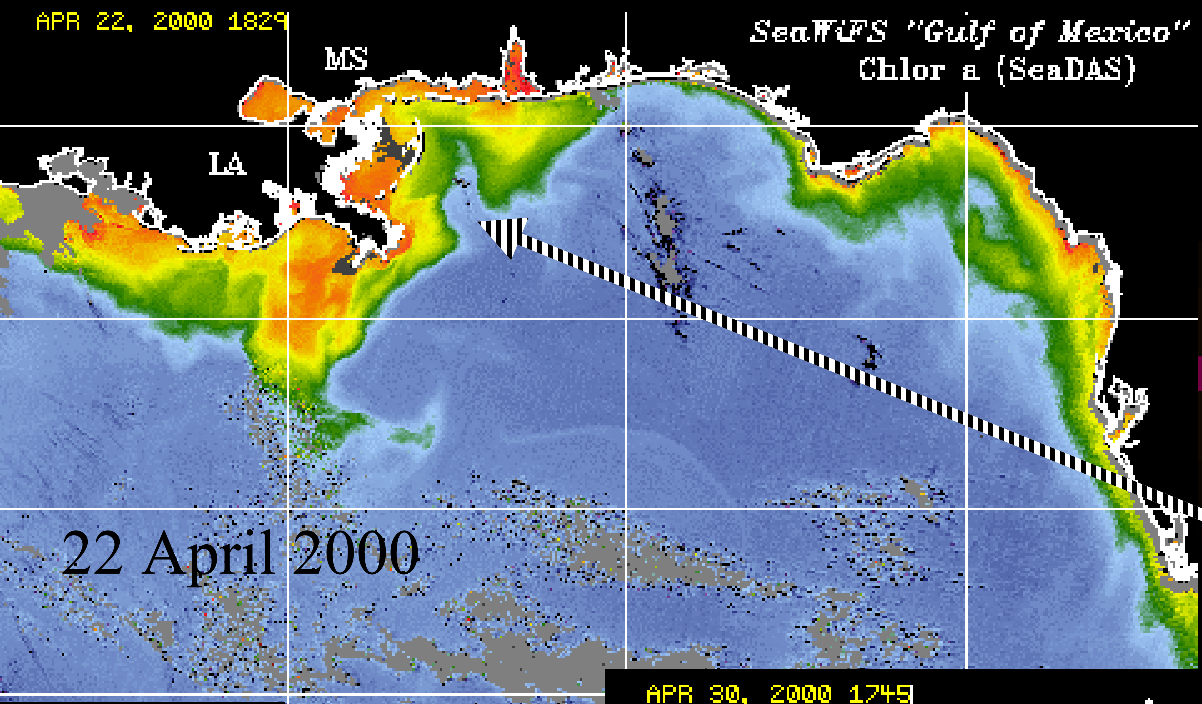
# Gulf of Mexico Sea Surface Height
## Blended T/P and ERS-2 sea surface height anomaly plus model mean

Leben, U. Colorado

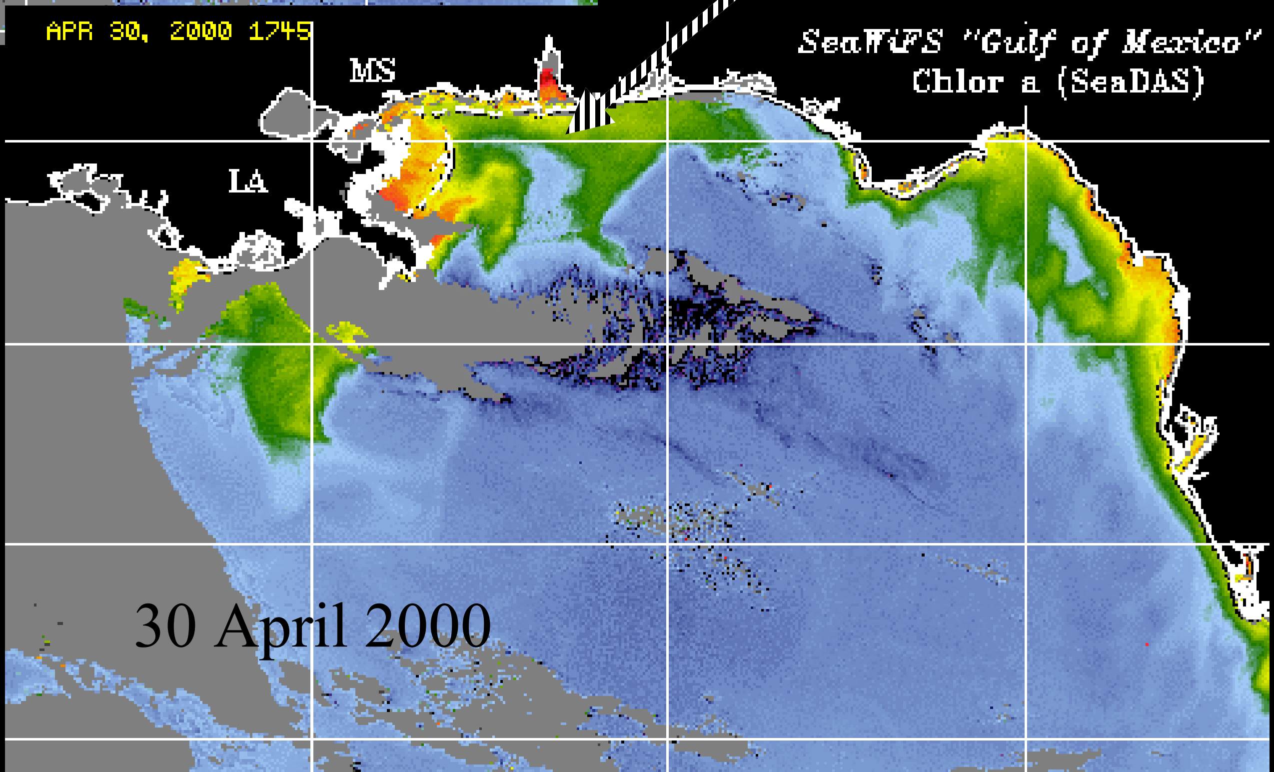



2.59 days ending 2000 Apr 15 23:00 UT

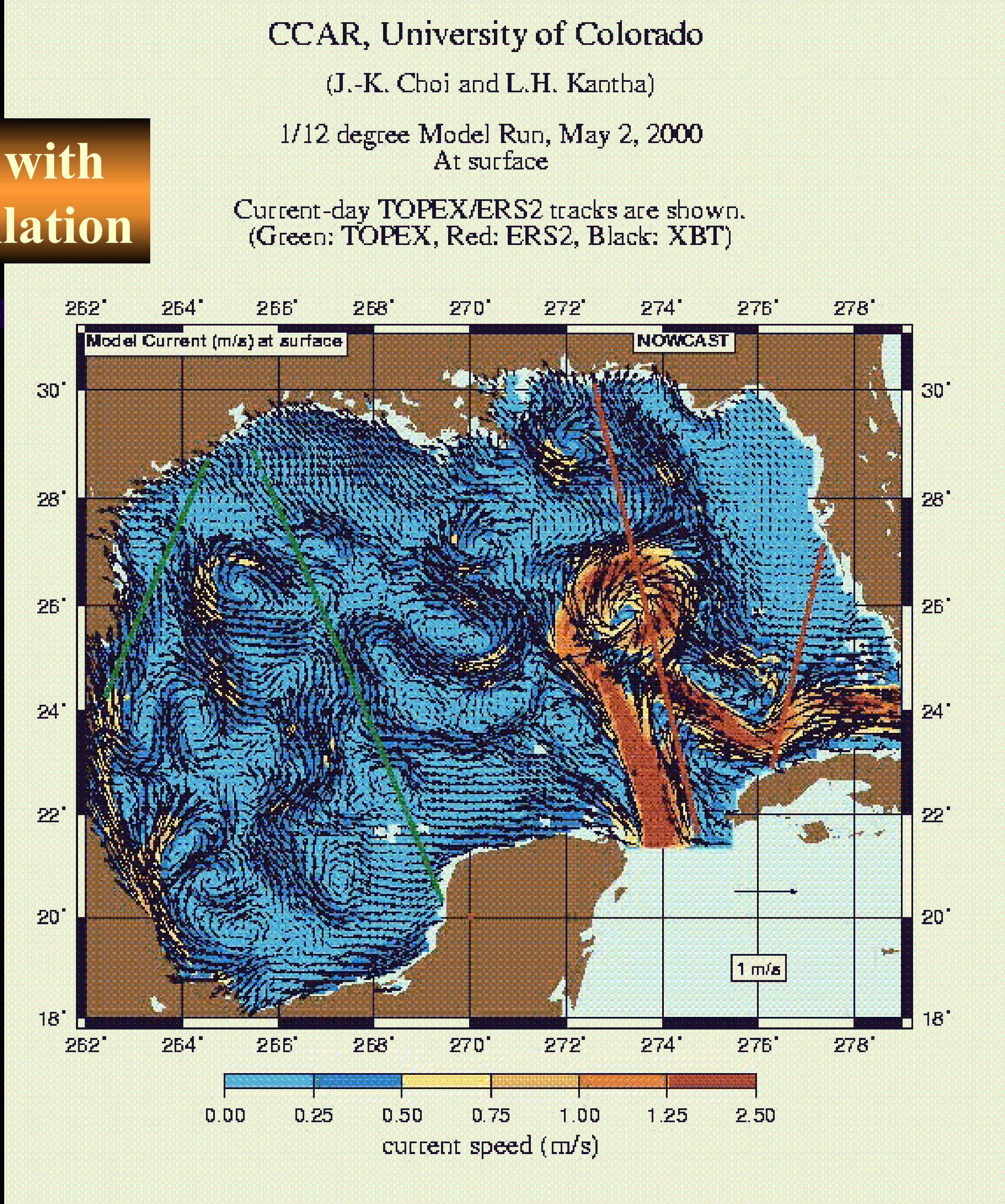
# Seawifs Chlor-a




Note intrusion of ‘blue’ water.



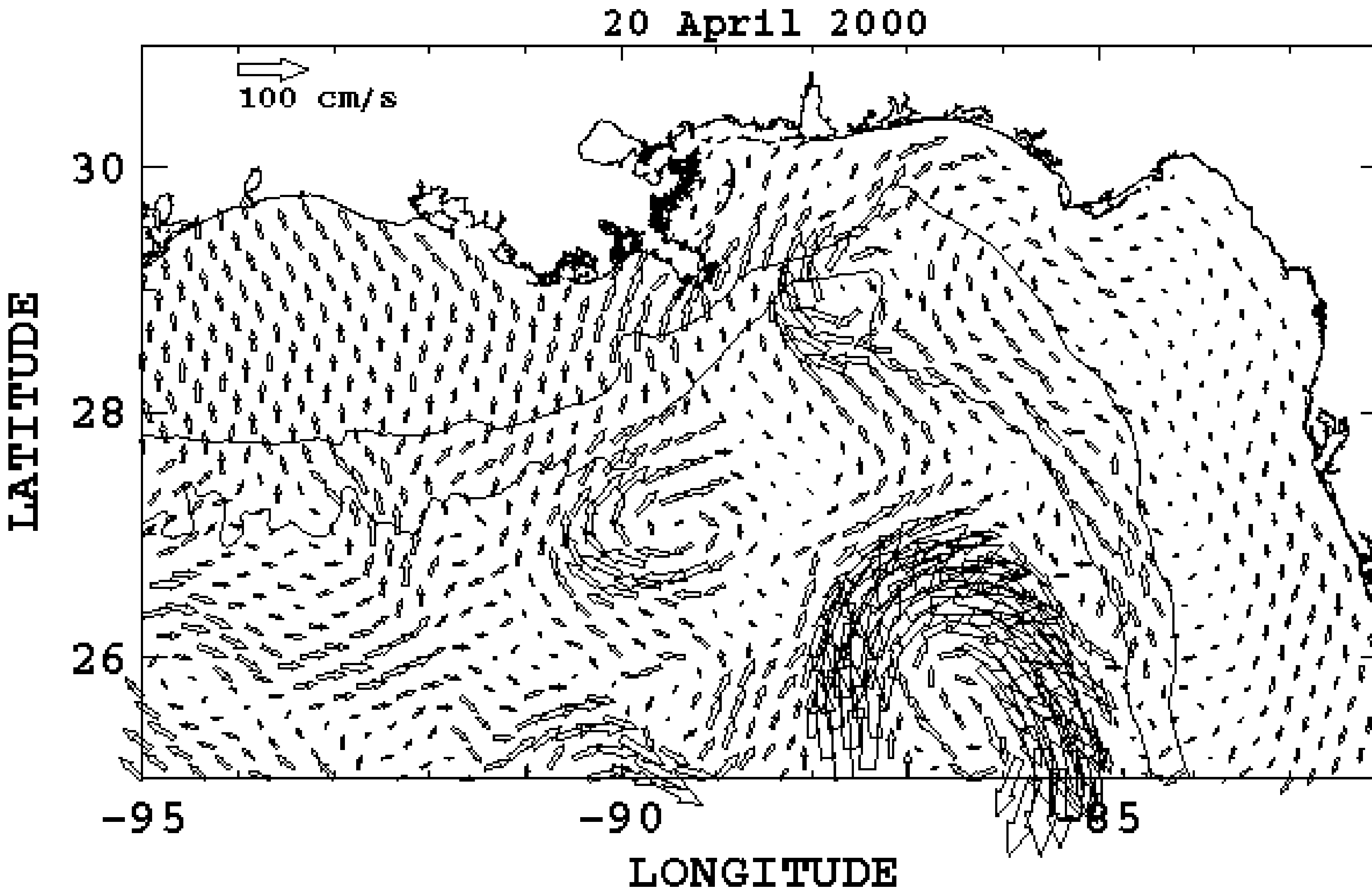
# Oil companies model with Altimeter data assimilation



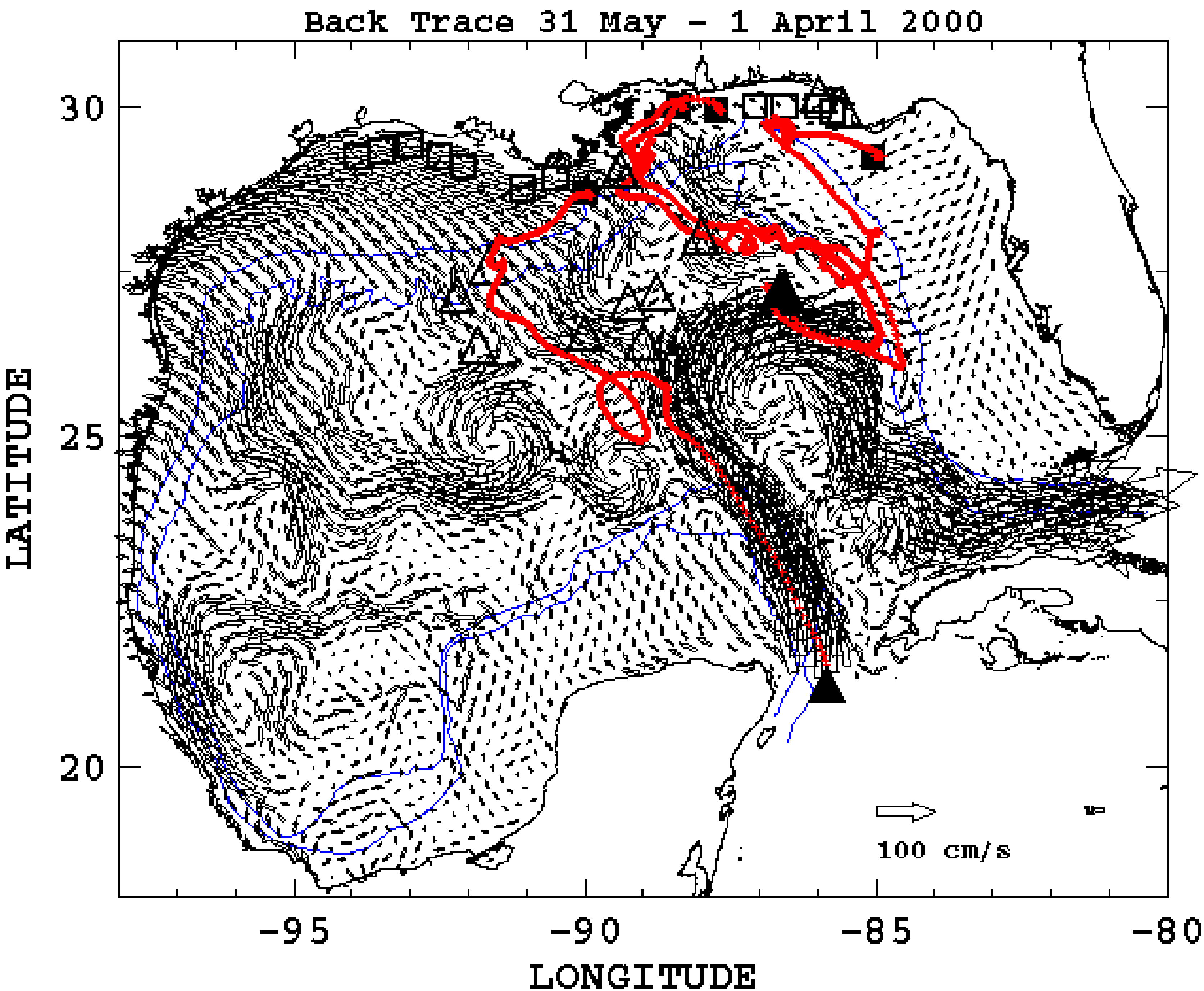
**Thanks to Lakshmi Kantha and Jei K. Choi, U.Colorado**

Numerical Model:

- Princeton Ocean Model (Sigma Coordinates)
- 21 levels in the vertical.
- 1/12 degree latitude/longitude resolution.
- Real Winds 6 hourly FNMOC.
- Sea surface damped to climate temp/salinity.
- Satellite altimetry assimilation.




**Model surface currents**



Back Trace 31 May - 1 April 2000
LATITUDE
LONGITUDE
30
25
20
-95
-90
-85
-80
100 cm/s

# Summary

* ***Phyllorhiza*** appear to have been brought into the Mississippi Bight in 2000 by the Loop Current and its spin-off eddies.

* By this model ***Phyllorhiza*** entered the Gulf on 1-2 April, 2000, left the Loop Current between 6-10 April and crossed onto the shelf around 20 April.

* Geological evidence for direct positive correlation between species longevity of benthic marine invertebrates and retention of planktonic larval stage (Jackson, 1974; Jabonski and Lutz, 1983).

This suggests that ‘probing’ for niches in new locations rather than physical adaptation may be a powerful strategy during times of climate change.